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UNITED STATES DEPARTMENT OF AGRICULTURE

DEPARTMENT BULLETIN No. 1136

Washington, D. C.

Issued May 12, 1923
Revised May, 1929

KILN DRYING HANDBOOK

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U. S. Department of Agriculture

By

ROLF THELEN, In Charge
Section of Timber Physics, Forest Products Laboratory, Forest Service

CONTENTS

	Page
Purpose	1
Moisture in wood	2
General principles of drying wood	7
Heat in the kiln	7
Humidity in the kiln	19
Air circulation in the kiln	26
Drying and drying stresses	31
Drying schedules	43
Miscellaneous features of drying	62
Types of kilns	69
Piling lumber for kiln drying	78
Details of kiln operation	83
Air seasoning	95

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By ROLF THELEN, *In Charge, Section of Timber Physics, Forest Products Laboratory, Forest Service*[1]

CONTENTS

	Page
Purpose	1
Moisture in wood	2
Moisture determination	3
Distribution of moisture in stock during drying	5
General principles of drying wood	7
Heat in the kiln	7
Sources of heat	7
Pipe coils and other radiators	8
Control of kiln temperature	12
Humidity in the kiln	19
Relative humidity	19
Humidity-measuring instruments	20
Control of kiln humidity	24
Air circulation in the kiln	26
Production of circulation	27
Measurement and control of circulation	29
Rate of circulation	29
Testing the circulation	30
Drying and drying stresses	31
Moisture gradient	31
Shrinkage	32
Drying defects caused by uneven skrinkage	33
Stress detection	37
Key for determining from stress sections the probable conditions in lumber during seasoning	39
Stress remedies	39
General rules for steaming	42
Drying schedules	43
Kiln samples	44
Use of the drying schedules presented here	47
General hardwood schedules	48
Drying schedules—Continued.	Page
General softwood schedules	50
Special schedules	53
Miscellaneous features of drying	62
Oscillating schedules	62
Drying by superheated steam	62
Drying periods	63
Final moisture content	64
Steaming sap gum	66
Seasoning specifications	67
Storage of kiln-dried stock	68
Moisture change in transit	69
Types of kilns	69
Progressive kilns	71
Natural-circulation compartment kilns	72
Condenser compartment kilns	74
Water-spray compartment kilns	74
External-blower compartment kilns	75
Internal-fan compartment kilns	75
Superheated-steam compartment kilns	77
Piling lumber for kiln drying	78
Flat piling	78
Box piling	80
Edge piling	81
Piling practice	82
Details of kiln operation	83
Periodic inspection of kiln	83
Calibration and adjustment of instruments	83
Location of instrument bulbs	89
The placing of kiln samples	91
The kiln run	91
Kiln records	92
Essential apparatus	94
Air seasoning	95

PURPOSE

The principal purpose of this publication is to present to the dry-kiln operator, in condensed and convenient form, the fundamental facts about the drying of wood that he must know in order to get

[1] Acknowledgment is made by the author to the members of the section of timber physics, both past and present, who are largely responsible for the development of the practical technic of kiln drying described in this bulletin. Further acknowledgment is made to the manufacturers of lumber, dry kilns, and kiln equipment who have assisted in obtaining and in commercial testing of the results presented here and in addition acknowledgment is made to the University of Wisconsin.

the most satisfactory results with his kiln. Naturally the major portion of the publication deals with the kiln drying of lumber, but specific suggestions for the drying of other partly manufactured wood specialities are also included. The general information is applicable to all kinds of drying.

No attempt has been made to present detailed data in substantiation of the information given. The conclusions, which have been tested out in commercial practice, are for the most part based on extensive investigations and experiments by the Forest Products Laboratory of the Forest Service, Department of Agriculture, Madison, Wis.

MOISTURE IN WOOD

The chief aim in seasoning wood, whether such drying takes place in the kiln or elsewhere, is to remove part of the moisture naturally present in it, which if allowed to remain would ordinarily interfere seriously with its use. The amount of moisture to be removed depends upon both the quantity present and the service for which the wood is intended. It is rarely necessary, except in test pieces, or even desirable to remove all the moisture, that is, to bring about an oven-dry condition.

Moisture in wood is commonly called sap, a word that has several meanings. Since lack of a precise definition causes much confusion, this bulletin will avoid the use of the term "sap."

The moisture in both sapwood and heartwood consists almost entirely of water, although it does contain small percentages of organic and mineral matter. In the sapwood these substances are principally sugars of various kinds, and in the heartwood they include tannins, coloring matter, and various other chemicals. For present purposes, sap will be considered as water only.

Water occurs in wood in two distinct forms, usually called "free" water and "imbibed" water. The free water is in the cell cavities, and the imbibed is in the cell walls. Imagine each cell of a piece of wood to be a small bucket made of some absorbent material. When such a bucket is filled with water, a certain quantity of the water is absorbed by the sides and bottom, in addition to the pailful which they inclose. The pailful is free water, that absorbed by the walls is imbibed water, and the sum of the two represents all the water the bucket, or the cell, can hold. A portion or even all of the free water can be removed from the cell without changing the amount of imbibed water in its walls, but when it has become empty further draining removes water from the walls themselves and they begin to dry out. The point at which the cell becomes empty while the walls are still full is called the "fiber-saturation point"; it has a very important bearing upon the process of drying and for that reason will be discussed more fully later.

In most living trees both heartwood and sapwood contain some free water. The amount, which depends on a number of factors, varies considerably, although sapwood almost always has more moisture than heartwood. Similarly the butt may contain much more than the top, as is evidenced by the sinker stock of redwood and of sugar pine. The season of the year in which trees are felled may have some influence upon the moisture in their sapwood, although this influence is never important.

Both species and place of growth have an important bearing upon the amount of moisture in living trees. Those growing in swampy regions are apt to contain much more moisture, and also are likely to be harder to dry, than similar upland species; the oaks are an excellent illustration of this fact. On the other hand, certain species contain comparatively large amounts of water even though they normally grow under reasonably dry conditions. All variations such as these must be taken into consideration in the drafting of drying schedules and in actual drying operations.

MOISTURE DETERMINATION

To dry stock successfully, which includes knowing when it has reached the proper degree of dryness, the operator must be able to determine at any time the amount of moisture in the wood. Although there are several methods of doing this the following is the one customarily used for lumber.

Crosscut the board or other stock at least 2 feet from one end, to avoid the effect of end drying, and then again about three-quarters of an inch from the first cut, thus gaining a section as wide and as thick as the original stock and three-quarters of an inch long, measured with the grain. Remove all loose splinters from the section and weigh it immediately on a sensitive scale. Record the weight, which is called "original weight." Place the section in a drying oven kept at a temperature of about 212° F., leaving it there until it no longer loses weight, usually from 12 to 24 hours, although sometimes longer. Leaving a section in the oven for more than the required time may cause an appreciable error in the result. Remove the section from the oven and again weigh it; the scale reading will be the "oven-dry" weight of the wood—the weight of the actual wood substance. The difference between the original weight and the oven-dry weight is the weight of the water originally in the section.

In calculating the moisture percentage, first divide the difference between the original weight and the oven-dry weight by the latter, and then multiply by 100. The formula is as follow:

$$\text{Moisture content in per cent, based on oven-dry weight} = \frac{\text{original weight} - \text{oven-dry weight}}{\text{oven-dry weight}} \times 100 \quad (1)$$

Thus, if the original weight is 180 grams and the oven-dry weight is 150, a difference of 30 grams, the moisture percentage will be $\frac{30 \text{ grams}}{150 \text{ grams}} \times 100 = 20$ per cent. The moisture content so determined is based on the oven-dry weight of the wood, a practice almost universal. One of the important advantages of this basis is that the percentages of moisture are directly proportional to their actual weights; if for instance a given piece of wood contains 5 per cent moisture, the actual weight of the moisture in it is just half of the value obtaining when the piece has 10 per cent moisture.

It is possible, however, to base the moisture content of wood upon the original weight. This system is occasionally employed for mois-

ture determinations by those who are accustomed to use it for other purposes. The formula for calculation follows:

$$\text{Moisture content in per cent, based on original weight} = \frac{\text{original weight} - \text{oven-dry weight}}{\text{original weight}} \times 100 \quad (2)$$

In the first of these systems the oven-dry weight is called 100 per cent; in the second, the original weight is so called.

Although the system basing the moisture content on the original weight is not recommended for wood sections, conversion of moisture percentages from one system to the other sometimes is necessary. The following formulas permit such conversion:

$$\text{Moisture content based on oven-dry weight} = \frac{\text{moisture content based on original weight}}{1 - \text{moisture content based on original weight}} \quad (3)$$

$$\text{Moisture content based on original weight} = \frac{\text{moisture content based on oven-dry weight}}{1 + \text{moisture content based on oven-dry weight}} \quad (4)$$

In these two conversion formulas, the values of moisture content must be expressed as decimals. For example, if the moisture content of a piece of wood based on the dry weight is 25 per cent, and on the green weight 20 per cent, the formulas will read, respectively, as follows:

$$\text{Moisture content based on oven-dry weight} = \frac{0.20}{1 - 0.20} = \frac{0.20}{0.80} = 0.25$$

$$\text{Moisture content based on original weight} = \frac{0.25}{1 + 0.25} = \frac{0.25}{1.25} = 0.20$$

BALANCES

Any system of weights may be used for moisture sections, but the metric is more convenient than the others and is preferable for this reason. The unit weight of the metric system is the gram; a fraction of a gram is conveniently expressed as a decimal.

The choice of a balance is largely a matter of service requirements, of personal preference, and of first cost. For general kiln use it should have a capacity of 200 to 250 grams and should be sensitive to 0.1 gram. These requirements are met by the ordinary analytical balance in which the two pans are suspended from an overhead beam and which has separate weights; by the torsion balance, with its beams below the pans and with separate weights; and by the Harvard trip scale, which has the beam located under the pans and is provided both with separate weights and with a scale beam and rider reading to 10 grams by steps of 0.1 gram. (Pl. 1, A.) Kiln operators, however, commonly prefer the multiple-beam balance, which has only one pan, suspended from the main beam, and which is provided with sliding weights. It has a normal capacity of 111 grams, with an auxiliary loose weight that nearly doubles this capacity. Agate

bearings improve its sensitivity, which with ordinary metal bearings is 0.05 gram and with agate is about 0.02 gram. An agate-bearing triple-beam balance of good quality (pl. 1, B) is reasonably satisfactory also for small pieces, such as moisture distribution sections. (See below.) Balances can be obtained from most dry-kiln manufacturers and from dealers in scientific instruments.

Several forms of calculating scales, developed particularly for moisture-determination work, have merit; some types permit direct reading of the moisture content, without calculation.

The large scale required for kiln samples is described on page 88, and pages 94 and 95 present a list of necessary equipment.

DRYING OVENS

Several kinds of ovens for the drying out of moisture sections are on the market. Most of them are electrically heated and practically all of these in addition are provided with thermostatic control, which keeps the temperature accurately at the desired point. (Pl. 2, A.) Steam-heated ovens, which are convenient and are free from trouble, will be found excellent where a suitable supply of steam is continuously available. Ovens of this kind are commonly homemade. The walls and the doors can be of galvanized iron, built hollow with a 1½-inch space filled with mineral wool, and the heating element can be conveniently made of 1-inch or 1¼-inch pipe; both the insulation and the heating surface must be adequate for the heating capacity of the steam supply. Ventilators should be fitted to the top, and provision should be made under the steam pipes for the entrance of fresh air. The temperature is usually regulated by means of a reducing valve on the steam line and dampers on the ventilators. For each cubic foot of volume above the heating coils in the oven there should be at least 1½ square feet of heating surface and 6 square inches of ventilator area. Shelves should be provided for the moisture sections.

Various kinds of hot plates are available in place of ovens to dry out moisture sections. It is customary to use very thin sections with these hot plates and to leave them on only a short time—15 to 45 minutes. Such a hot plate is cheaper than a regular oven, and in the hands of a skillful operator can be made to yield good results, but it can not be recommended except as a makeshift.

DISTRIBUTION OF MOISTURE IN STOCK DURING DRYING

It is very helpful, except in the simplest kinds of drying, to know how the moisture is distributed through the cross section of the board or other piece of stock, and to secure this information moisture distributions are made. In so doing a moisture section is obtained in the usual manner, but instead of being weighed as a whole, it is cut or split so as to separate the core from the outer portion, called the shell, and distinct moisture determinations are made on each part. The shell will usually be in two or four pieces, which can be weighed most conveniently as a single unit. For thick stock it may be desirable to divide the sections into three units, a shell, an intermediate part, and a core. The further procedure is then precisely the same as before, the pieces of the intermediate part being weighed

as a unit just as are those of the shell. To secure fully satisfactory results, the weights should be taken with an accuracy close to 0.01 gram.

Figure 1 illustrates the method of cutting the moisture and the distribution sections. While recommended practice is to cut both a full section and a distribution section whenever a distribution test is to be made, it is not absolutely necessary, since the average moisture content may be secured with reasonable accuracy from the dis-

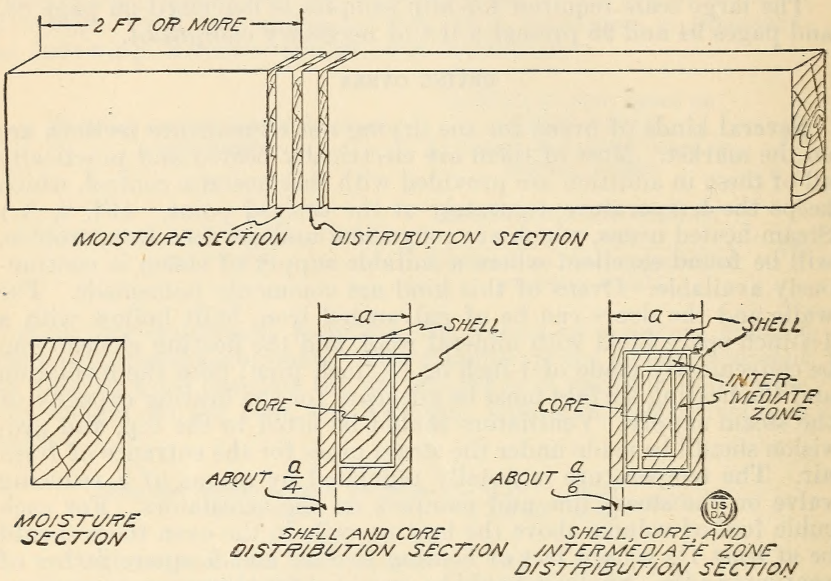


FIGURE 1.—Method of cutting sections from a piece of wood for moisture-content and moisture-distribution determinations

tribution section alone by assuming the combined original weights of all the pieces to be the original weight of the section, and similarly with the dry weight. The entire calculation may for example be as follows:

Shell

Original weight=60 Oven-dry weight=50

$$\text{Moisture} = \frac{10 \times 100}{50} = 20 \text{ per cent}$$

Core

Original weight=100 Oven-dry weight=80

$$\text{Moisture} = \frac{20 \times 100}{80} = 25 \text{ per cent}$$

Section

Original weight=160 Oven-dry weight =130

$$\text{Moisture} = \frac{30 \times 100}{130} = 23.1 \text{ per cent}$$

GENERAL PRINCIPLES OF DRYING WOOD

The drying of wood is a very complex process, concerning many phases of which information is still lacking. It is not essential, however, that the operator understand all of the details of the movement of moisture through wood and all of the attendant phenomena. He may take it for granted, for the time being, that the moisture in each piece tends to distribute itself evenly, moving from the more moist parts to the drier ones.

The movement of moisture through wood is affected by a number of controllable external factors. Only two of them need to be considered here—the temperature and the humidity of the atmosphere surrounding the wood, that is, of the air in the kiln. Circulation of this air, adequate in both uniformity and volume, is necessary in order to control its temperature and its humidity; in fact the success of a kiln-drying operation depends very largely upon the proper regulation of heat, humidity, and circulation.

HEAT IN THE KILN

Heat is required, in kiln drying, to evaporate the moisture from the wood, whether the temperature of the kiln is high or low. The higher permissible temperatures, however, increase the rate of transfusion of moisture to the surface of the wood and thus permit more rapid drying. The temperature that is correct for the purpose is determined in each case largely by the species of the wood and by the thickness and the shape of the individual pieces; these factors are modified somewhat by the use requirements for the finished stock. Commercial-kiln temperatures range from 100 to 250° F.

A kiln temperature above that of the surrounding atmosphere introduces a problem in the heating of buildings, imposing upon the heating system the added burden of replacing promptly the heat lost through its walls. The higher the kiln temperature, the greater will be the heat losses.

The relation between the total heat input to the kiln and the heat required to evaporate the moisture from the charge in it is highly variable, even if steam used for humidification is omitted from the heat input. Such factors as species of wood, thickness of lumber, rate of drying, character of drying schedule, and type of kiln, have an important effect upon this relation. Under the best possible conditions it is commercially practical to secure the evaporation of a pound of water for about 1¼ pounds of steam put into the heating coils. Average heat efficiency, however, is much lower than this. Economy of steam is of importance in many plants, but sacrifice of quality in drying seldom if ever pays a dividend.

SOURCES OF HEAT

Many methods have been used to heat kilns, and although most of them are obsolete or impractical, brief mention will be made of the principal ones.

Direct furnace heat.—A fire built on the ground or in a crude fireplace is the source of heat in the direct-furnace-heat method. The

products of combustion pass directly upward through the lumber, which is open piled on a platform above the fire. Kilns of this type are known as smoke kilns. A number of years ago they were very popular through the southern pine region, but their use is now limited almost entirely to small portable or semiportable mills in that region.

Indirect furnace heat.—As in an ordinary hot-air furnace, the indirect-furnace-heat system leads the incoming air around the fire pot and the radiators on its way to the kiln, and the products of combustion pass directly up the chimney instead of going through the kiln.

Gas.—Occasionally natural or artificial gas is used to heat small dry kilns, the burners being arranged much as in an ordinary household gas oven.

Electricity.—Electric heat offers many advantages in the way of cleanliness, ease of control, and efficient installation, but the cost of operation is in most cases prohibitive. The successful operation of a small electric-kiln installation is reported in the trade press.

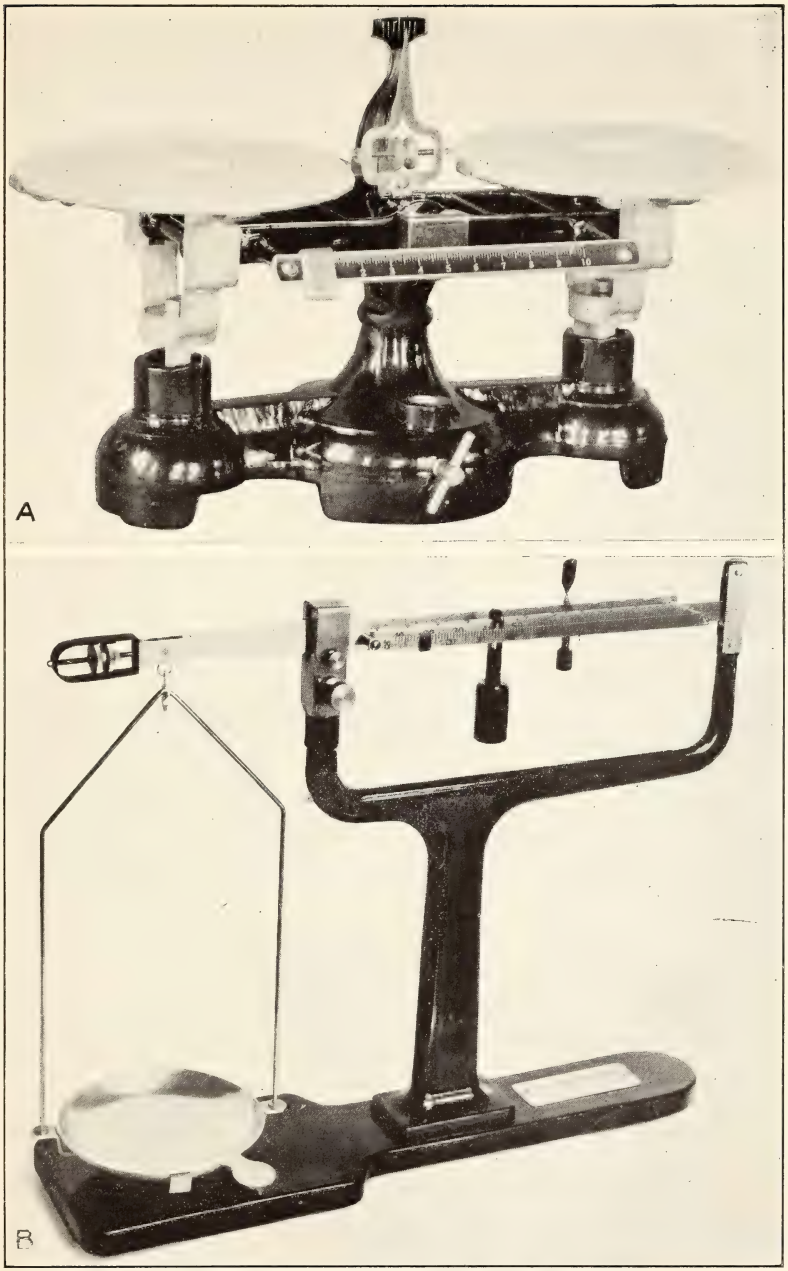
Hot water.—The hot-water system can readily be adapted to the heating of kilns that do not demand too high a temperature. A suitable hot-water supply rarely is available, however, in the absence of steam.

Steam.—At present steam is almost universally employed for heating dry kilns of all types, and consequently a knowledge of its proper use is essential to intelligent kiln operation. It may be either high pressure, above 10 pounds per square inch, or low pressure, below 10 pounds. High-pressure steam is almost invariably live steam, that is, steam direct from the boilers; low-pressure steam is frequently exhaust steam, that which has passed through engine, pump, or turbine on its way from the boilers to the kilns. As a rule high-pressure steam is far drier than low-pressure, principally because exhaust steam generally carries with it much water condensed in its passage through the engine or other unit in which it has done work. The steam cooling in the kiln radiators gives up its heat to the kiln air and the charge of lumber is dried accordingly.

PIPE COILS AND OTHER RADIATORS

The form, construction, and arrangement of the kiln radiators is of importance. Those built of pipe coils are most common; the coils are made of ordinary merchant pipe or of wrought-iron pipe, the rust-resisting qualities of the latter making it particularly suitable for severe corrosion conditions. Among the advantages of such radiators are low first cost, ease of manufacture and of installation, ready adaptability to a great range of shapes and of sizes, and ease of repair by any shop mechanic.

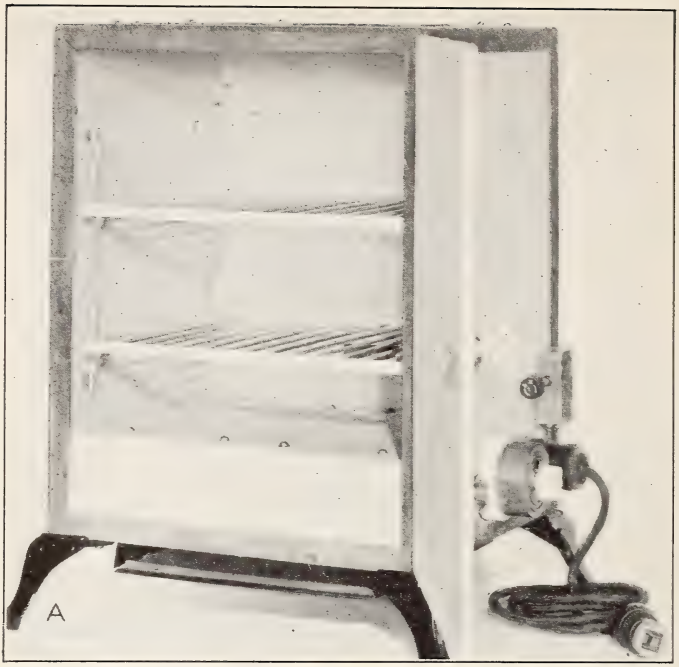
A good pipe coil must possess several essentials: (1) the size, the shape, and the location to heat properly and in some cases to recirculate the air in the kiln; (2) mechanical strength and durability, with provision for the expansion and contraction of the individual pipes in the coil; (3) provision for the ready escape of air and of water of condensation from the entire system; and (4) provision for adjustment in the amount of active heating surface, by cutting some pipes

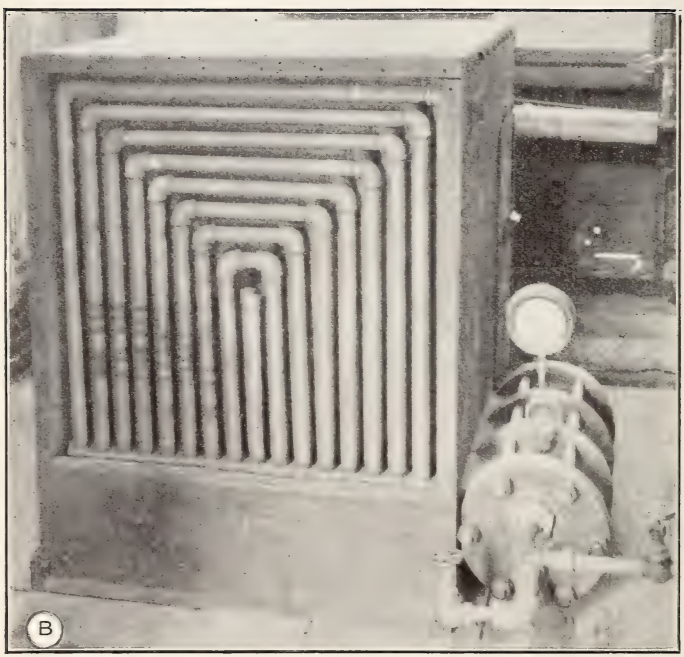


BALANCES FOR WEIGHING MOISTURE SECTIONS

A.—This type of balance is usually known as the Harvard trip scale. The one illustrated has a maximum capacity of 5,000 grams. The capacity of the scale beam and its rider is 10 grams, reading by tenths. The balance, which has agate bearings, is sensitive to 0.1 gram under light loads and to 0.5 gram at full load.

B.—The triple-beam balance illustrated has agate bearings and consequently is sensative to 0.02 gram or less. The three beams with their respective poises obviate the necessity of a set of loose weights. Their capacities are as follows: Central beam and poise, 100 grams; rear, 10 grams; and front, 1 gram; making a total capacity of 111 grams for the balance as shown. The addition of an auxiliary loose weight, similar to a counterpoise (not shown), increases the reading of the balance by 100 grams; this weight must be used only on the 100-gram notch of the central beam. With it, the maximum total capacity possible is 201 grams.

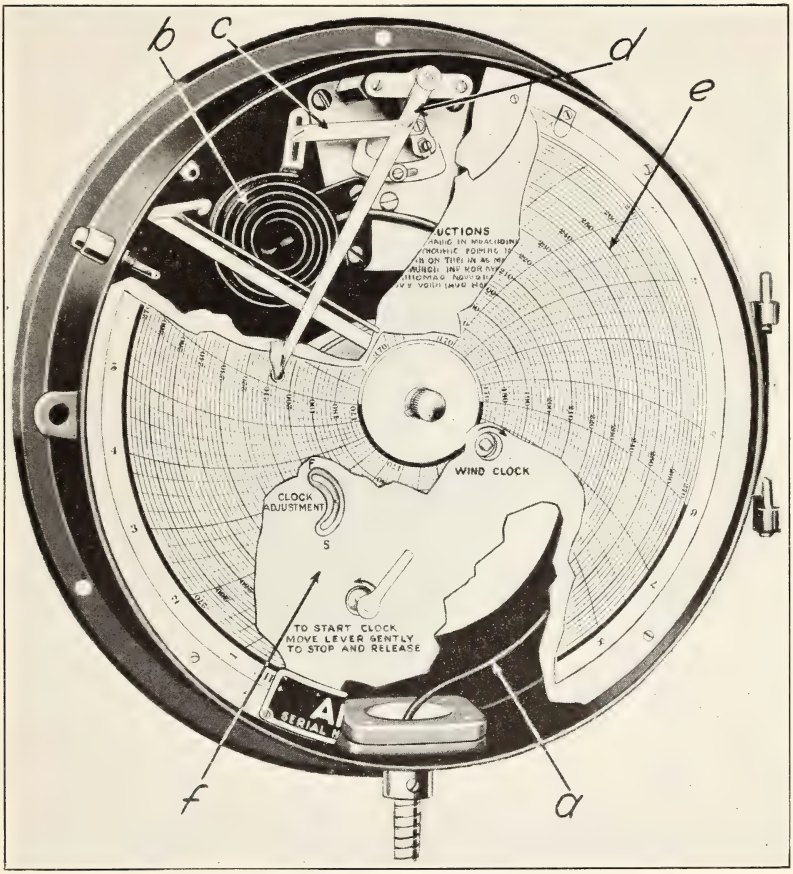




AN AUXILIARY AND A MAIN APPLIANCE FOR DRYING

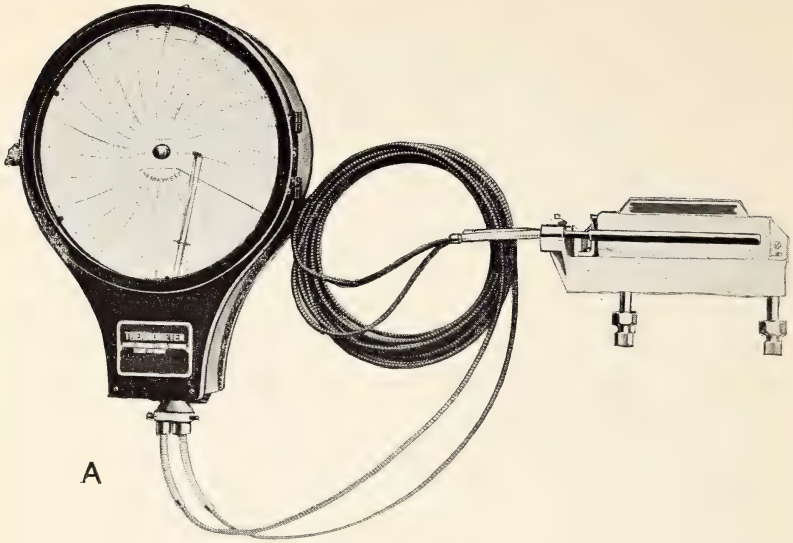
A.—Typical electric oven for drying moisture sections. Electric ovens can be obtained in various sizes and qualities to suit individual requirements. Each one should always be provided with an automatic thermostat, accurate to within 2° F., to keep the temperature constant.

B.—Typical heating coils for external-blower compartment kilns. Steam enters the coils through the upper half of the receiver at the right, and condensate is drawn off from the lower half. The cast-iron base into which the pipes are screwed is cored to provide separate paths for the steam and the condensate.

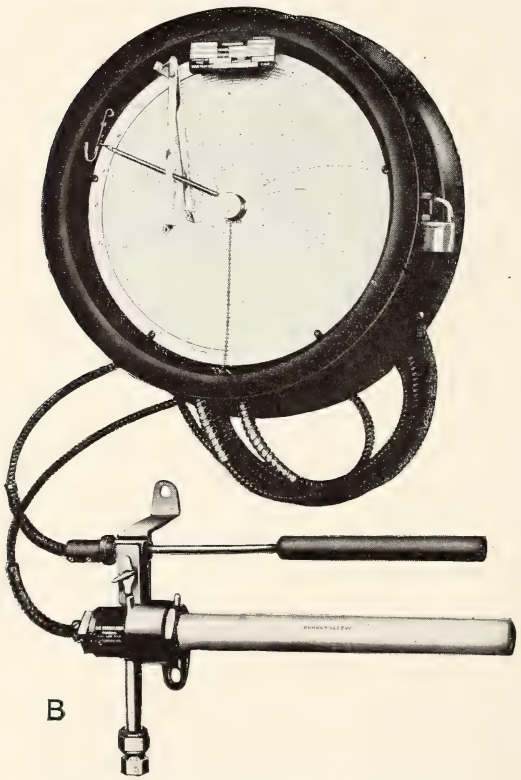


A Recording Thermometer

Changes in pressure produced in the bulb (not illustrated) by changes in the temperature of the air surrounding it are transmitted through the tube *a* to the spiral pressure-sensitive element *b*, which is made of flattened tubing. The pressure changes cause the free end (the outer one) of the element *b* to move back and forth. This movement is transmitted through the link *c* to the arm *d*, which through its pen records the change on the chart *e*. The chart is rotated by means of the clock *f*. Seven-day charts are customary in kiln work, although one-day are also used.



A



B

EXTENSION-TUBE RECORDING PSYCHROMETERS

A.—A recording psychrometer is a 2-pen recording thermometer having a water box or a porous sleeve for one of the bulbs. The instrument illustrated, the vapor-filled type, is provided with an overflow-type water box and a wet wick. The wick, which incloses the wet bulb and dips into the water in the water box, is directly behind the dry bulb in the illustration.

B.—This instrument, which is intended for the same use as the one in A, is equipped with a porous sleeve in place of the water box. In the illustration the porous sleeve, which incloses the wet bulb, is shown directly below the dry bulb. Water under slight pressure is fed to the inside of the sleeve, filling the annular space between the sleeve and the wet bulb. Then, seeping out through the porous wall, it evaporates from the outer surface, thus producing the drop in temperature commonly called "wet-bulb depression." The flow of water through the sleeve must be sufficient to keep its outer surface wet.

in or out. Since it is difficult to combine all these essentials in the highest degree in any one type of coil, different kinds have been found best adapted for various special conditions, in which a single requirement is likely to predominate.

Pipe coils for dry-kiln heating fall into two general classes, known as header and as return-bend coils. In header coils, a number of pipes lead from the same supply main, called a header, and return to a drip main, also a header, usually but not always located at the other end of the kiln. In the return-bend type, however, the lengths of pipe in each group are connected end to end by means of return bends; steam enters the top length, and condensate is removed from the bottom one. Figure 2 illustrates various types of pipe coils.

Most kiln coils, regardless of detail characteristics, are located in the kiln proper, commonly between or under the rails. Many different methods of arranging, particularly of grouping, these heating coils have been designed to meet widely varying individual drying requirements. In most pipe-coil kilns, the pipes run lengthwise of the kiln, and are ordinarily grouped as plain header coils or as return-bend header coils. In several recent designs of cross-piled kilns, however, the pipes run crosswise, with a group under each truck. These groups are sometimes subdivided so that various numbers of pipes in each one may be used as desired.

PLAIN HEADER COIL

The plain header coil is one of the commonest forms of heating unit in present kiln practice. To secure satisfactory results, especially in the quantity and the uniformity of the heat supply, coils of this type must be so designed and operated that there is steam in them all the time, and they must be arranged to drain freely. To meet the first requirement, the coils in each kiln must usually be divided into several groups, and just enough pipes in each group are used to give the desired amount of heat when the steam is on full all or most of the time. Trouble from uneven heating of header coils is confined largely to kilns having excessive heating surface, especially those with nonthrottling thermostatic control.

RETURN-BEND COIL

In the return-bend type the top pipes in each group become hot first, since the steam must pass through them before reaching the lower ones. Each pipe runs the full length of the kiln, however, and heating of the air will be practically uniform from end to end. The return-bend type also has disadvantages, among which are its first cost and the amount of head room that the vertical arrangement of the piping demands; the head room must be sufficient not only for the individual pipes and the return bends, but also for at least 0.1 inch of downward pitch per foot from the supply end to the discharge end of each group. This pitch causes adjacent pipes to form a V with each other, and consequently the head room necessary increases rapidly with the length of the kiln. The return-bend coil is better adapted for short kilns requiring accurate temperature control and even heat distribution than for long kilns.

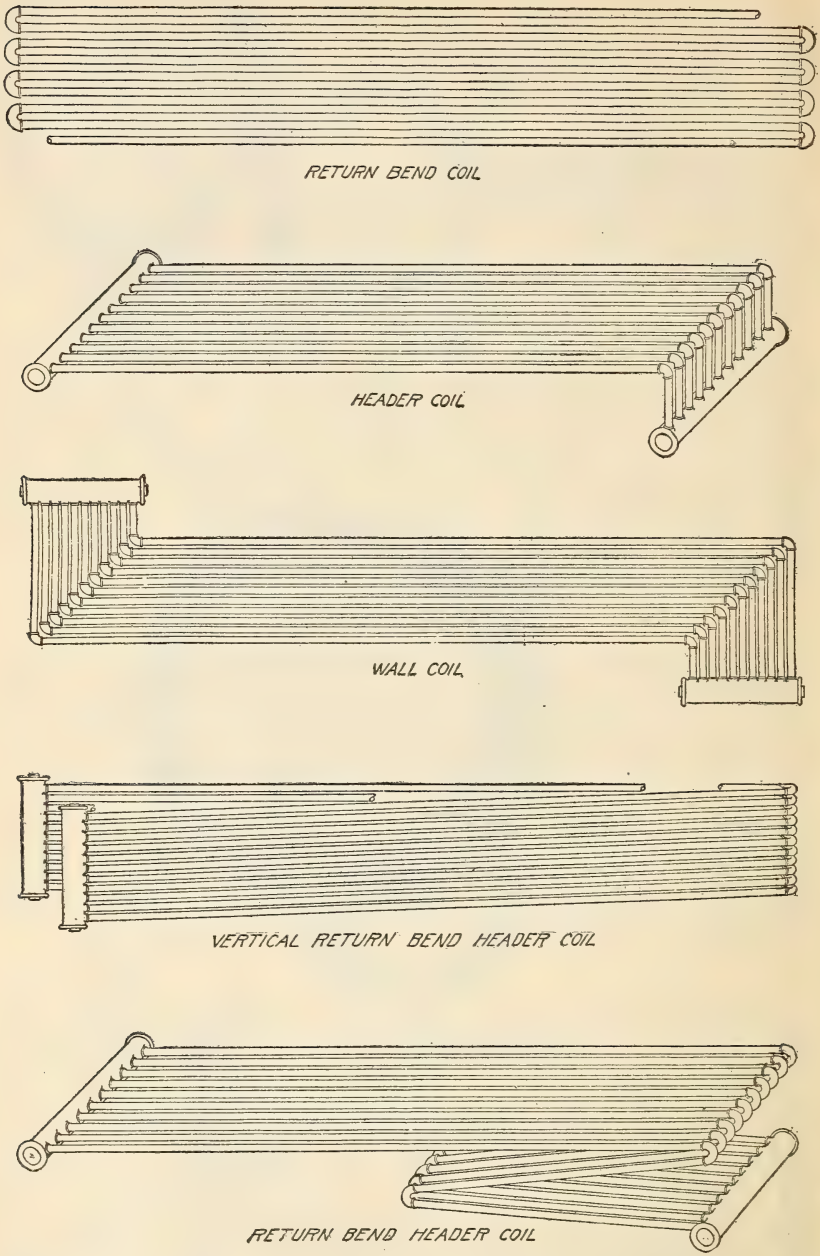


FIGURE 2.—Typical pipe coils for heating dry kilns. All such coils provide for expansion and contraction of individual pipes and for free flow of condensed steam to the drain end. Header coils and return-bend header coils of various types are most common; vertical return-bend coils are used in short kilns that require uniformity of temperature. In many cases header coils are made up with two rows of pipe instead of only one. The type of wall coil illustrated is ordinarily known as a Z coil; in dry-kiln work it is usually placed horizontally

COMPROMISE TYPES

Various modifications of the two primary types, which in different degrees retain some advantages of both and eliminate some disadvantages, have been introduced. Among these are the return-bend header coil, with horizontal headers and two or more layers of pipe connected by means of return bends; and the vertical header coil, with both headers at one end of the kiln and either return bends or elbows and nipples at the other end. Such compromise types have merit and will operate advantageously under conditions to which they are adapted.

WALL COILS

Although pipe-coil radiators on the side wall can not be recommended for general application, they properly form a part of the design of certain types of kilns. These radiators need not differ materially from those located under the lumber. In fact, the great amount of head room available for them facilitates getting rid of the condensate from almost any type of coil; it even permits the use of return-bend coils in long kilns without the sacrifice of the pitch required for proper drainage.

CAST-IRON RADIATORS

Cast-iron radiators have been used in a few kilns, but their high first cost has no doubt been an important factor in preventing their more general adoption. Although they can be obtained in a variety of shapes and sizes, in general they are best adapted to conditions that require concentrated radiation. Care must be exercised, especially with low-pressure steam, to secure proper venting of the air from them, and it is desirable to have some means of determining from the outside of the kiln whether they are working.

EXTERNAL HEATING UNITS

External fan kilns of several types have the heating units located outside of the kiln, as shown in Plate 2, B. These units are usually of the standard types common in blower systems for heating buildings. Substantially all of them consist of compactly arranged groups of pipe coils made up with cast headers, each of which forms the base of a unit, although sometimes special forms of cast-iron radiators are used. Good practice equips each unit with valves, so that various portions of it may be cut out as desired. Such heaters give little trouble, since their design permits unusually easy removal of air and of water and the short pipes are free from difficulties caused by uneven expansion and contraction.

CEILING COILS

In addition to the heating equipment described, some kilns are equipped with ceiling coils. These usually consist of a few runs of pipe spaced a foot or more apart and hung an inch or two below the ceiling. Since their function is to replace the heat continuously lost through the ceiling, thus preventing the ceiling from acting as a condenser, they are made entirely independent of the main heating units, so that they may be in service most or all of the time. During

cold weather especially, and particularly whenever high humidities are used, a ceiling that lacks such local heating is likely to accumulate a great deal of condensation which, dripping down upon the lumber, interferes seriously with humidity control.

CONTROL OF KILN TEMPERATURE

Correct determination of the temperature in the kiln is essential to proper control of the drying process and consequently deserves much more time and attention than it usually receives. Thermometers, the only temperature-determining instruments in kiln practice, may be grouped in two classes, indicators and recorders.

INDICATING THERMOMETERS

Many kinds of indicating thermometers are available, and care must be exercised to select reliable instruments. The very cheap ones, with separate scales stamped on metal strips attached to the case, are not accurate enough for kiln work and should be avoided. A number of better grades also have separate scales, but the highest-grade thermometers have their graduations etched on the glass stem; these can be obtained with or without a metal protecting sleeve. Plate 9, C illustrates such a thermometer in a sleeve; Plate 9, B, *a* shows sufficiently its appearance without one. Further information on the subject is given on page 84.

Indicating glass-stem thermometers for kiln work are almost invariably of the mercury-filled type, though sometimes alcohol-filled ones are selected.

Most kiln operators find it very desirable to determine both temperature and humidity at the same time; this is commonly done by means of the wet and dry bulb hygrometer, which will be discussed later. Since such a hygrometer indicates temperature, there is little need, where it is used, for a separate thermometer in the kiln. Each operator, however, should have at least one dependable etched-stem thermometer available for purposes of comparison and calibration.

RECORDING THERMOMETERS

Recording thermometers for kiln work are almost without exception of the extension-tube type. In such recorders the sensitive element, called a bulb, is connected to the instrument by a capillary tube of suitable length. The tube, which is usually protected by flexible armor, ends in a hollow spring or other pressure-sensitive element in the case. This spring, which may be any one of several different types, is so constructed that changes in internal pressure cause in it a movement that, transmitted from its free end by a lever system to a pen arm playing over a chart, is recorded graphically. The chart receiving the record, either a 1-day or a 7-day form, is rotated by a clock movement, which is wound whenever the chart is changed.

Plate 3 shows the case of an extension-tube recording thermometer, cut away to display the internal mechanism, and Plate 4 illustrates complete double-pen instruments. The construction appearing in Plates 10, 11, and 12 is similar.

Three types of extension-tube recording thermometers are in common use. The principal difference among them is in the material

filling the tube system, and accordingly the three are known, respectively, as mercury-filled, gas-filled, and vapor-filled thermometers.

In dry-kiln work, both the tube and the case of the recording thermometer are subject to variable temperatures, which during operation of the kiln differ from that of the bulb; the thermometer is intended to record bulb temperature alone. Fluctuations in the tube and in case temperatures affect the accuracy of the instrument, especially with the mercury-filled and the gas-filled types. In these types, ordinary variations in any one of three temperatures, bulb, tube, and case, will change appreciably the reading of the thermometer, except when compensation is made for variations in case temperature. The vapor-filled instrument, on the other hand, is nearly free from errors caused by tube and case temperatures, provided that its bulb is large enough and contains the proper amount of liquid, since the pressure of vapor in the tube and in the hollow spring then is virtually the vapor pressure of the volatile liquid in the bulb, at bulb temperature.

Practically all extension-tube instruments now sold for dry-kiln work are of the vapor-filled type. This includes recorders, air-operated controllers, and recorder controllers.

Charts recording temperature for 1-week periods are satisfactory for most purposes; those at least 10 inches in diameter are preferable. The divisions on the charts of mercury-filled and of gas-filled instruments are uniform throughout the working range. This is not true of most vapor-filled instruments, because the vapor pressure does not vary in direct proportion to the temperature. One manufacturer, however, has produced a vapor-filled recording thermometer with uniform chart, by introducing a cam into the pen-arm movement.

REDUCING VALVES

The temperature in the kiln is controlled by means of auxiliary apparatus, such as valves and thermostats. The pipe leading from the steam main to the kiln is almost always provided with a globe or a gate valve, by which the entire steam supply to the kiln can be turned on or shut off. This valve also permits hand control of the temperature in case no other means is available.

When boiler steam is used for heating dry kilns, it often happens, especially with low-temperature schedules, that the pressure in the steam mains is higher than is necessary for the proper temperature in the kiln; this pressure commonly fluctuates materially over the 24 hours of the day. A pressure-reducing valve (pl. 5) between the steam main and the kiln is likely to be desirable in such a situation. If a battery of kilns operates at high steam pressures, a single reducing valve may be made to serve the entire battery, but where steam at a customary boiler pressure is used either to augment the supply of exhaust steam or as the entire supply for low-pressure systems, it will be necessary to install two reducing valves in tandem, the first one reducing to perhaps 10 pounds and the second making the final step. The first valve will be a heavy, rugged type and the second a more sensitive one, capable of close adjustment. In an installation of this kind a steam receiver or a length or two of pipe should be placed between the two reducing valves to provide a cushion, thus preventing the first one from chattering. The varia-

tions in the reduced pressure are less than those in the high-pressure main.

Whenever a battery of kilns is run part time on exhaust steam and part time on live steam it is highly desirable, if not essential, to have a reducer between the boilers and the exhaust-steam main to the kilns, so that the live steam may be supplied to this main at about the exhaust pressure. If desired, the back-pressure valve on the exhaust line and the reducing valve on the boiler line can be so adjusted that the boiler line will automatically supply any deficit in the exhaust steam. To accomplish this, the back-pressure valve should be set at a slightly higher pressure than the reducing valve; tandem reducing valves are required with such an arrangement. Steam pressure gauges should invariably be provided on a live-and-exhaust-steam heating system so that the operator may always know just what pressures he has available.

The intelligent manipulation of reducing valves assists materially in maintaining good temperature control. The pressure to the kilns may be so adjusted that it is barely sufficient to keep the desired temperature with the steam-control valve wide open. Excessive temperature rises can thus be prevented, and the coils may in consequence be kept full of steam most of the time. Under hand control this arrangement is unusually sensitive, since a comparatively large change in the setting of the hand valve will then make only a small change in the amount of steam supplied. Hand control, of course, is sensitive to weather changes and the temperature of a hand-controlled kiln will fluctuate with the outside temperature unless continual readjustment is made.

The use of automatic control valves is recommended for practically all kinds of kiln drying, because with them a temperature more even than that possible with hand control may be maintained, injury from excessive temperatures may be avoided, and loss of time from unnecesarily low temperatures may be prevented. Automatic control effects material savings in steam and in time of attendance over hand control.

Reducing valves should always be so installed that they can readily be removed for repairs. If the kiln is provided with automatic control, the control valve will usually be placed next to the kiln.

AUTOMATIC TEMPERATURE CONTROL

Automatic control of temperature is secured by means of instruments known as thermostats, which regulate the amount of steam supplied to the kiln. Two classes of thermostats, self-contained and auxiliary-operated, are in common use in dry kilns. The self-contained ones combine in a single unit a motor valve and a liquid or vapor filled tube system comprising the bulb—which is placed in the kiln—the capillary connecting tube, and the motor head. The temperature variations in the kiln change the pressure inside the bulb, which in turn causes corresponding pressure changes in the motor head. This action results in a movement of the valve, the stem of which is connected to the motor head, which is a bellows-type diaphragm. The valve itself is usually of the balanced type, to provide ease of movement. A constant counter pressure, tending to keep the valve open by opposing the varying pressure in the motor head, is

provided by means of an adjustable spring or of sliding weights, and the instrument (pl. 6) is set for the desired temperature by changing the tension of the spring or the position of the weights; the setting is made by the slow method of trial and error.

The principal advantages of the self-contained thermostat are that no auxiliary source of power is required for its operation and that its first cost is comparatively small. An important disadvantage lies in the fact that instruments of this type fail to respond quickly to changes in temperature, with the result that they do not work well under conditions requiring wide fluctuations in the amount of steam supplied. In addition, changes in the temperature of the motor head may cause changes in the setting of the instrument, so that it will operate at temperatures higher or lower than the one desired. This irregularity occurs when the temperature of the head is as high as that of the bulb; the head accordingly should not be placed in an operating room the temperature of which is likely to approach that in the kiln. Further, the self-contained type is not quite so sensitive as the auxiliary-operated; although the manufacturers claim regulation within 2° F. of the temperature for which the instrument is set, this range is sometimes exceeded where the circulation is inadequate. The principal field of usefulness of the self-contained thermostat is a progressive kiln, where the temperature at the control bulb is intended to be constant, rather than in a compartment kiln, the temperature of which is varied from time to time. The auxiliary-operated instruments, on the other hand, are supposed to control with a variation of only 1° F. and in kilns having ample circulation usually maintain this accuracy.

Auxiliary-operated thermostats are made in various types. Some use electric power, some water or steam pressure, and some compressed air, and again certain of them work under various combinations of these means. Most of the auxiliary-operated thermostats in dry-kiln service, however, are of the air-operated type. The temperature-sensitive element may be bimetallic, but in kiln work it is usually the extension-tube type, with bulb, capillary tube, and pressure-sensitive hollow spring or capsule filled with liquid or with vapor. (Pl. 7 and fig. 3.) The movement of the free end of the hollow spring or of the capsule top in response to temperature changes in the kiln is transmitted to a small valve connected on one side with a supply of compressed air at about 15 to 25 pounds pressure per square inch and on the other side with a diaphragm-motor valve on the steam main—the diaphragm is sometimes called a bellows. The small air valve is so arranged, in instruments using direct-acting diaphragm valves, that as the temperature rises, air pressure is admitted to the head of the diaphragm-motor valve. This forces the diaphragm down, closing the main valve and shutting off the steam from the kiln. As the temperature falls, the air pressure is shut off, and a means of escape is provided for the air in the valve head. The valve then opens through spring action, again admitting steam to the kiln. Reverse-acting diaphragm valves are so constructed that the air pressure opens them and the springs close them. Direct-acting and reverse-acting valves can not be used interchangeably with the same thermostat.

The advantage of the reverse-acting type is that a failure of the air supply causes the valves to shut, which prevents the possibility of a dangerous rise in temperature. The same effect may be secured in a battery of direct-acting thermostats by putting a single reverse-acting valve in the steam main and connecting it direct to the air supply.

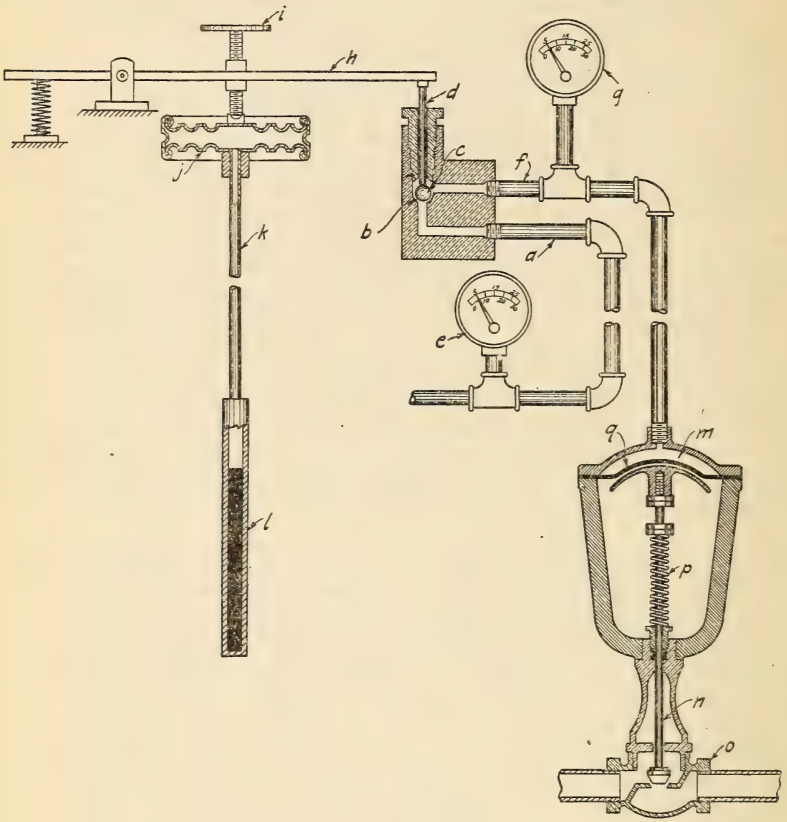
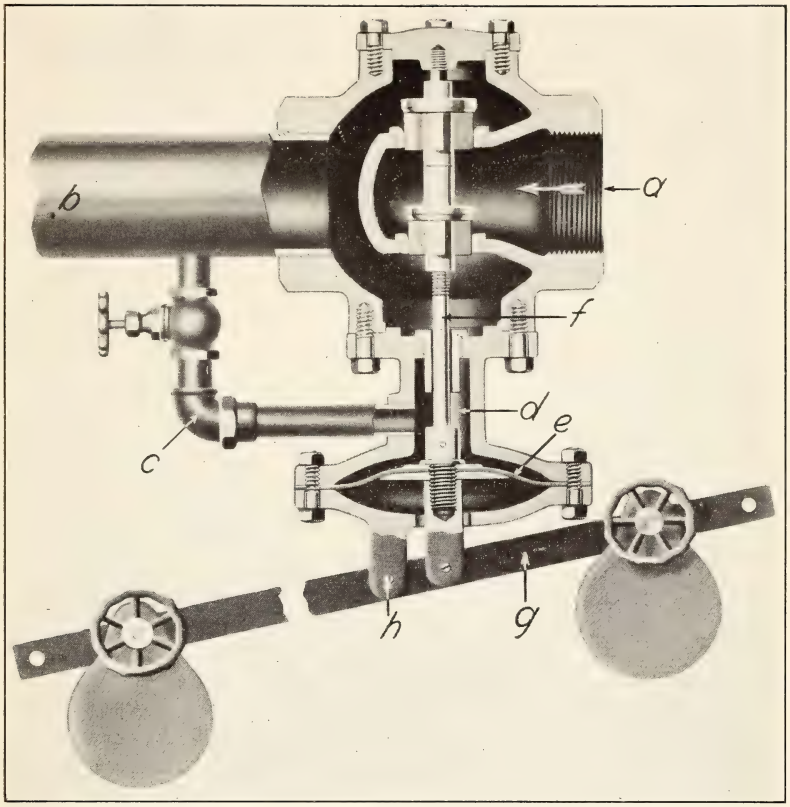
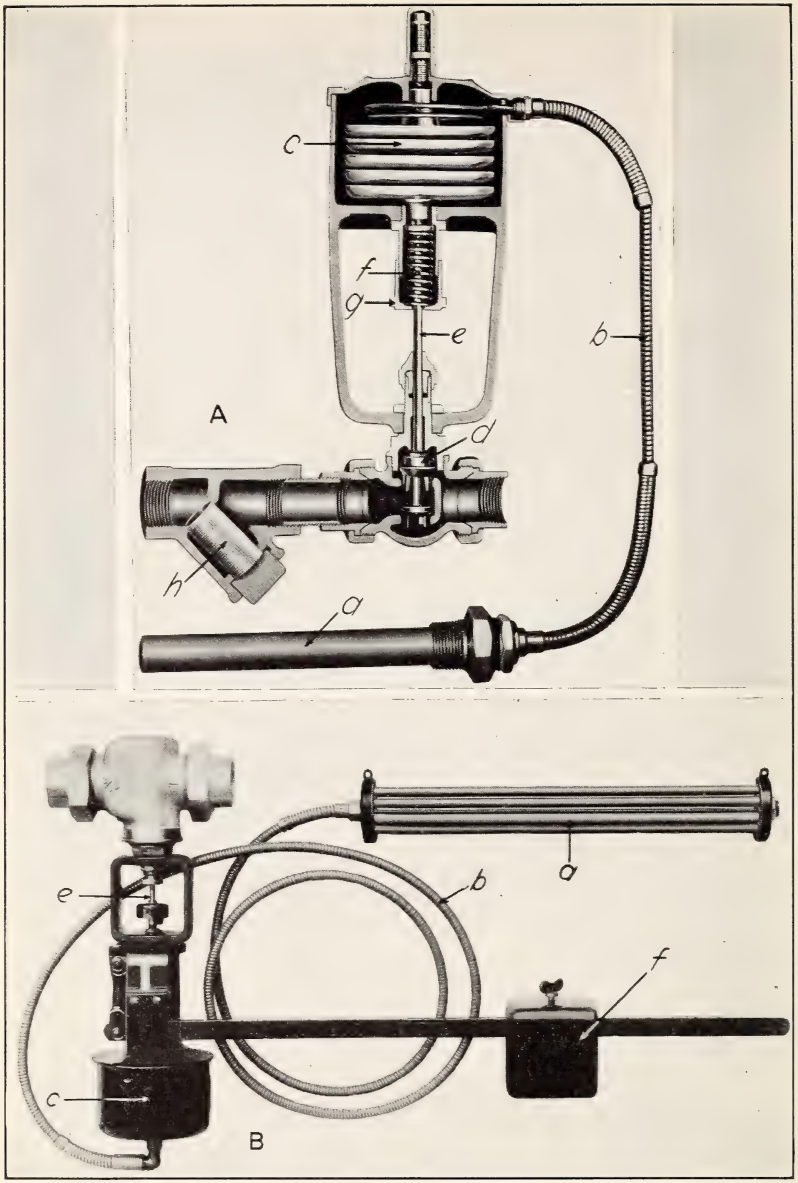


FIGURE 3.—Cross section of an air-operated thermostat and a direct-acting diaphragm-motor valve. This diagram shows the method of operation and illustrates the details of a common type of air-operated thermostat, a type in which the flow of air to and from the diaphragm-motor valve is controlled directly by an air valve, without the use of an intermediate valve and bellows. Opening and closing of the diaphragm-motor valve is accomplished through the medium of compressed air, at a pressure of about 15 pounds to the square inch. When air is admitted to the chamber *m* it forces downward the diaphragm *q* and with it the valve and valve stem *n*; the valve, seating in the valve body *o*, shuts off the flow of steam. When the air pressure is released, the spring *p*, aided by the steam pressure acting on the under side of the valve, raises the valve, thus opening the steam passage. The supply of air to the diaphragm-motor valve is controlled by a small valve *c*, as follows: When the temperature of the bulb *l*, which is in the kiln, rises in response to increased kiln temperature, increased pressure is transmitted through the capillary extension tube *k* to the spring capsule *j*, which expands, its top rising as a result, carrying with it the adjusting screw *i* and the lever *h*. This movement allows the air pressure from the supply line *a* to raise the valve *c* and the valve stem *d*. Air then flows around the valve through the pipe *f*, into the chamber *m*. When the temperature of the bulb *l* falls, the reverse action takes place, and the valve *c* is seated, shutting off the air supply to the diaphragm-motor valve. The pressure of the air in the chamber *m* is then relieved through leakage of air around the valve stem *d*, which is made a loose fit for this purpose. As the pressure is relieved, the valve and valve stem *n* rise. The gauge *e* indicates the pressure of the air supply, and *g* that acting on the diaphragm *q*



A PRESSURE-REDUCING VALVE FOR STEAM, DESIGNED ESPECIALLY FOR LOW REDUCED PRESSURES

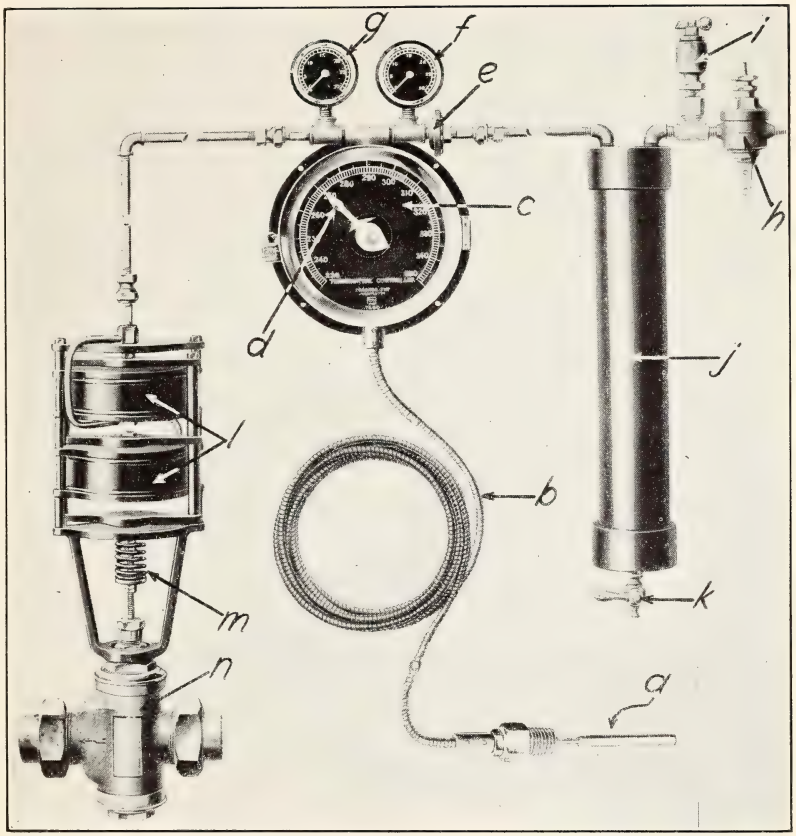
Steam enters at *a*, is reduced somewhat in pressure by the throttling action of the restricted passages while flowing through the valve, and passes out at *b*, reaching its final pressure value by expansion in the low-pressure space. The pipe *c* transmits the reduced pressure to the chamber *d*, which is closed at the bottom by the rubber diaphragm *e*, to which is attached the valve stem *f*. The pressure on the diaphragm tends to move the valve stem downward, an action that would close the valve and shut off the high-pressure steam. This action is resisted by the weights on the arm *g*, which is pivoted at *h*. When the left-hand weight is placed far out, as is done in practice, its thrust presses upward on the stem *f*, tending to open the valve. When steam is actually flowing through the valve, the stem comes to the position that permits a flow just sufficient to produce the pressure on the diaphragm required to balance the effect of the weights. Thus the valve adjusts itself as needed to maintain the reduced pressure desired, the amount of which is determined by the setting of the sliding weights. The pair of equal weights shown reduces chattering more than a single weight would; unequal weights, permitting also the convenience of rough and fine adjustment, are supplied by some makers.



SELF-CONTAINED THERMOSTATS

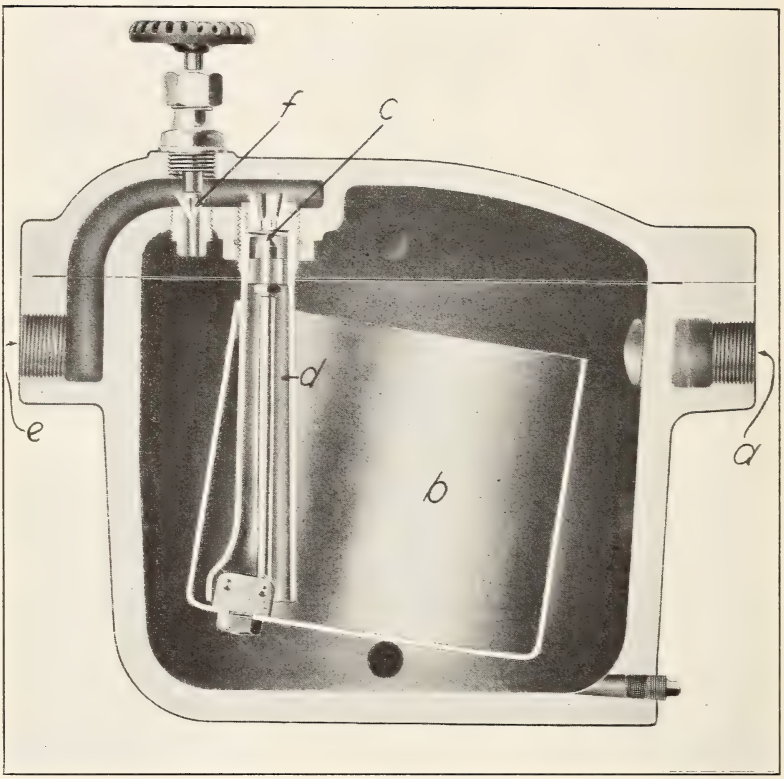
A.—This instrument does not require compressed air for operation, but depends entirely upon the pressure changes produced by variation in the temperature of the bulb *a*. Increase in pressure, which is transmitted through the tube *b* to the diaphragm motor *c*, tends to press down the balanced valve *d* and its stem *e*. Such a tendency is resisted by the spring *f*, the pressure of which can be adjusted by the spring housing *g* for any desired temperature within the range of the thermostat. When the temperature of the bulb *a* rises above that for which the thermostat is set, the diaphragm motor starts to close the valve, thus throttling down the steam supply, and when the temperature drops the action is reversed. In dry-kiln work conditions are usually close enough to constant so that the valve does not need to open or to close entirely, remaining in a partially open position. The strainer *h*, which must be cleaned occasionally, prevents chips and dirt from entering the valve and causing breakage. The union connection on the bulb is not necessary for dry-kiln work. The accurate working range for self-contained thermostats is usually about 40° to 50° F.

B.—Operating upon the same principle as the one shown in A, this instrument differs from the other chiefly in having a sliding weight for temperature adjustment in place of a spring. Corresponding parts are correspondingly lettered in the two illustrations. The bulb *a* is made up of a number of cylindrical tubes, to increase the surface-volume ratio and thus make the thermostat faster in its response to temperature changes.



AN AIR-OPERATED THERMOSTAT

Pressure changes in the bulb *a*, which is placed in the dry kiln, are transmitted through the extension tube *b* to the pressure-sensitive element in the case *c* of the instrument. The pointer *d* serves to set the instrument for the desired temperature. Air enters from the right, passing first through a reducing valve *h* and a drip chamber *j*, which is provided with a drain cock *k*. A safety valve *i* is supplied to prevent excessive pressure within the system, and a filter *e* keeps dirt from entering and clogging the fine air passages. The pressure gauges *f* and *g* show, respectively, the air pressures in the supply line and in the motor head of the valve. In the instrument illustrated, the valve *n* is of the reverse-acting type; that is, the valve in its normal position is closed by the action of the spring *m*, and is opened by air pressure in the motor head *l*, which is made in two sections. The purpose of such reverse action is to obtain automatic shutting off of the steam supply in case the air pressure fails.



A BUCKET STEAM TRAP

This type frequently is also called an open-float trap. Condensate enters from the heating system through the inlet *a*, flowing first to the bottom of the trap and then rising around *b* which at that time acts as a float. When the water has risen high enough, it overflows into *b*, which now functions as a bucket, eventually filling *b* sufficiently to tilt the bucket downward into the position shown. In such tilting the valve *c* is drawn away from its seat and consequently the pressure in the system forces the water upward through the pipe *d*, past the opening at *c*, and out through the outlet *e*. After a sufficient amount of water has been blown out, the returning buoyancy of the emptying bucket causes it to float upward, closing the valve *c*. This type of trap can be so balanced that the level of the water in the bucket never drops low enough to allow steam to escape. The by-pass or blow-off *f* provides a ready means of blowing out air or of assisting in the removal of excessive amounts of condensate, especially when the system is first started up; the by-pass in some makes is placed near the bottom of the trap, opposite the drain plug, discharging directly into the air so as to certainly avoid back pressure in the outlet *e* from the traps of other kilns.

Some types of air-operated thermostats are equipped with graduated dials, indicating the instrument adjustment, and with two air-pressure gauges, one indicating the pressure in the air-supply line and the other the air pressure in the motor head, which shows when the valve is open or closed. This information is useful to the operator when he is making new temperature adjustments.

Various combination instruments can be secured for different services; one type consists of a recording thermometer and an air-operated thermostat. Additional information concerning thermostats will be found under "Humidity in the kiln."

DISTRIBUTION OF ACTIVE HEATING SURFACE

After the steam has passed through the various valves in the supply piping, it enters the steam coils proper. If the coils are in one large unit, steam enters all of the pipes at the supply header at one time. This is a disadvantage when the kiln is operating under the low temperatures customary at the beginning of a run because the small amount of steam then required condenses on the large pipe surface it thus encounters before it penetrates any great distance into the coil; the result is uneven heating. The coils may, however, be divided into several smaller units, each of which can be controlled by a gate or a globe valve. In the latter case, enough units should be turned on to produce, if unregulated, a kiln temperature only slightly in excess of that desired. Care must be exercised to select the active units so that the kiln will be heated uniformly throughout.

STEAM TRAPS

Steam imparts its heat mainly through condensation. The water resulting must be continuously removed from the heating coils; otherwise they fill with it and become cold. Various devices are employed to remove water from steam coils, and several patented systems are in use. For most dry kilns, steam traps that allow the water to escape but retain the steam are selected. They can be divided into two general classes, those depending upon temperature for their operation, and those depending upon the weight of the accumulated water. The first class is known as thermostatic and the second as gravity. Most thermostatic traps contain an operating bellows, commonly called a diaphragm, which is filled with a liquid, generally volatile, that expands suitably under heat. One end of the bellows is attached to the stem of a valve, a part of the trap, in such a way that expansion of the bellows closes the valve, and conversely. The trap is connected to the lowest point in the heating system, so that the condensate will readily drain into it.

The heating coils are cold and full of air, and the trap with its contracted bellows (diaphragm motor) is cold and open when steam is first turned on. The entering steam gradually displaces the air, which is driven out through the open trap. A certain amount of steam is condensed, and the resulting hot water, which is far heavier than the obstructing air, flows to the trap and then through it. Warmed by the water, the trap partly closes, because of the expansion of the liquid in the bellows, but remains slightly open until all

the air and the water have been forced out and steam starts blowing through. The temperature of the steam, higher than that of the water, causes the bellows to expand further, enough to close the trap completely. A screw adjustment to set the trap for various steam temperatures is necessary, since the temperature of saturated steam increases with the pressure. After the trap has closed, condensed steam accumulates back of it until the bellows cools and consequently contracts enough to allow the trap to open again, thus discharging the condensate. It is desirable to place the thermostatic traps and air valves in the operating room rather than in the hot kiln, since they will then be under closer supervision and, on account of cooling more quickly, will be more responsive.

Thermostatic traps are used only on heating systems operating under compartively low steam pressures—say, below 20 pounds per square inch. When the system is broken up into a number of units, a thermostatic trap is sometimes fitted to each unit.

Gravity traps are of various types, such as tilt, float, and bucket. Of these, the bucket is far and away the most popular type of dry-kiln trap; it is suitable for high and low pressure systems, can be made rugged, and is in general reliable and easy to repair. (Pl. 8.) The special kind known as a return trap is perhaps most suitable for the occasional cases in which the condensate is to be returned to the boiler direct from the trap. Most return traps are the tilt type, that is, the whole body of the device tilts up and down as it empties and fills, and this tilting opens and closes the valves that control the flow of the water.

AIR-RELIEF VALVES

Under certain circumstances the presence of air in the steam coils may prevent the steam from filling them, a situation that results in uneven and insufficient heating. Coils in this condition are said to be airbound; the obvious remedy is to remove the air. Air binding is usually confined to low-pressure heating systems that are equipped with gravity-type steam traps. Vacuum systems, low-pressure systems with thermostatic traps, and high-pressure systems should give no trouble from this cause. Adjusting the amount of active heating surface so that there is always some steam in the coils will avoid trouble from air binding. When thermostats of nonthrottling types are used, air is apt to get into the pipes each time the thermostat shuts off the steam. The customary remedy for air binding is to equip the heating system with an automatic air-relief valve, which permits the escape of air but prevents the escape of steam. These valves are thermostatically operated; the expansion of a bar or of a liquid-filled capsule closes them when hot, and the contraction opens them when cold. The connection for an air valve should, in general, be taken off near the bottom of the system, preferably near the trap, and should run as high as the steam piping; the actual tap should be made on the top, not the bottom, of a pipe or fitting.

VACUUM PUMPS

Kilns operating on low-pressure steam are sometimes equipped with a vacuum pump for the rapid removal of air and condensate from the coils. One pump is sufficient for a battery of kilns, each

heating coil being connected through a thermostatic trap to the pump suction main. Where the heating coils in a kiln are broken up into units, the best practice is to have a trap on each unit. Although the pump is very effective, the rapid relief obtained by it is not needed in most kilns.

HUMIDITY IN THE KILN

The earth's atmosphere, our air, is a mixture of many invisible gases, principally oxygen, nitrogen, and water vapor. The amount of water vapor in the air, which is termed humidity, is usually expressed either in grains per cubic foot or as a percentage of saturation; the first method of expression is called absolute humidity, and the second is called relative humidity. Fortunately, the amount of water vapor that a given amount of air can hold at a given temperature is a fixed quantity; when this quantity is present the air is said to be saturated.

The amount of water vapor at the saturation point of air increases rapidly with increase in temperature. At 60° F., merely 5.8 grains of water vapor saturate the ordinary atmosphere, whereas at 212° F., the boiling point of water under a pressure equal to that of a column of mercury 29.92 inches high, it will hold about 260 grains per cubic foot.

RELATIVE HUMIDITY

In kiln drying it is more convenient to express the amount of water vapor in the air in terms of relative humidity than as absolute humidity, and when the term "humidity" is used in this publication, relative humidity is meant. As already intimated, relative humidity is always expressed as a percentage of saturation.

The lower relative humidities represent dry air and the higher ones moist air. Air at a temperature of 125° F., for instance, can hold a maximum of 40 grains of water vapor per cubic foot. If a certain atmosphere at that temperature had only 10 grains of water per cubic foot it would have only ten-fortieths of the maximum amount it could hold, which is a relative humidity of 25 per cent. Air with 25 per cent relative humidity is comparatively dry. At 125° F., the relative humidity of air having 30 grains of water vapor would be thirty-fortieths, or 75 per cent; such air would be considered moist. Air at 155° F. can hold 80 grains per cubic foot, twice as much water vapor as at 125° F. At 155° F. air containing 10 grains of water per cubic foot would be very dry, having a relative humidity of only 12½ per cent, and air containing 30 grains per cubic foot would still be moderately dry, having a relative humidity of 37½ per cent.

The preceding examples may be expressed by the following formula:

$$\text{Relative humidity per cent} = \frac{\text{amount of water vapor actually present in a given space}}{\text{maximum amount of water vapor possible (the saturation value) in the same space under the same temperature}} \times 100$$

At any given temperature dry air is heavier than moist air, and hot air always is lighter than cold air at the same relative humidity and the same pressure. When water is evaporated from wood, the

heat required for evaporation is absorbed from the air that carries away the water vapor, with resultant cooling of the air; the net effect in consequence is to make the air heavier, since the increase in weight brought about by the cooling outweighs the decrease caused by the increase in humidity.

The humidity of the surrounding air not only determines largely the rate at which materials will dry, but it also determines the extent to which they can be dried; there is a definite balance between the humidity of the air and the moisture content of wood. With minor variations, all kinds of wood held long enough in an atmosphere of constant temperature and constant humidity will come to the same moisture content, which is called the "equilibrium moisture content."

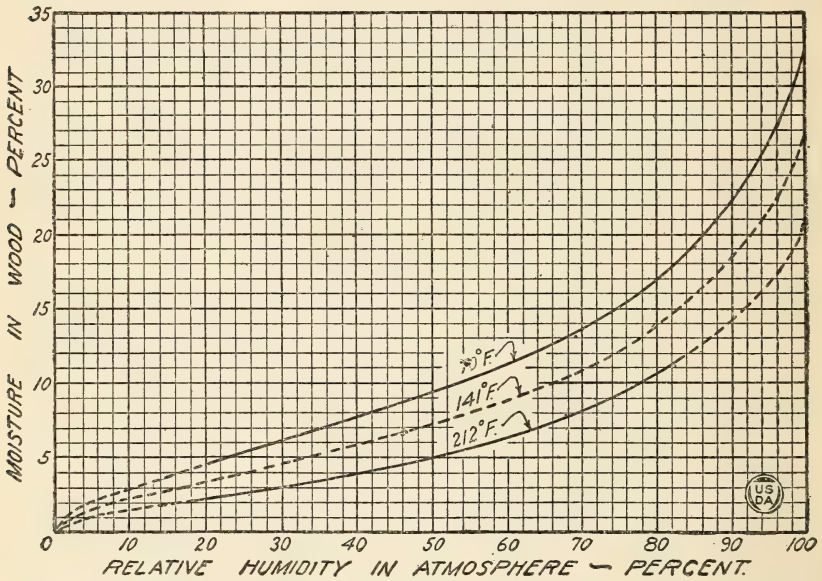


FIGURE 4.—Relation of the equilibrium moisture content of wood to the relative humidity of the surrounding atmosphere, at three temperatures

The time required for this adjustment varies with different species, other factors being the same. The relation between humidity in the air and moisture in the wood is an important one, since it is closely related to all drying schedules and, further, determines the extent to which wood for use under specified conditions of temperature and humidity should be dried. Figure 4 presents curves showing the humidity-moisture relation at three temperatures.

HUMIDITY-MEASURING INSTRUMENTS

Since humidity determines the drying characteristics of air at any given temperature, the control of humidity in the kiln is of prime importance. It is essential that the moisture be removed from the wood surface at the maximum safe drying rate. If the humidity is too low the wood will dry too fast and will be injured; if the humidity is too high the drying will be slow and expensive.

Humidity may be measured in a number of different ways, but the wet and dry bulb thermometer is almost universally used for such measurement in dry kilns. (Pl. 9, A.) This instrument is also known as a hygrometer and as a psychrometer. The silk or muslin wick for one of the two thermometers of the instrument, kept moist by the reservoir of water into which it dips, is cooled a certain amount by the evaporation of water from its surface when it is exposed to a breeze of nonsaturated air, and in turn it cools the wet bulb it incloses, thus causing the wet-bulb temperature indication to drop. The amount of cooling is constant for any given temperature and humidity, provided that the reservoir contains water enough to keep the wick moist and that the velocity of the cooling air is sufficient. If the amount of the cooling, called wet-bulb depression, and the temperature of the air are known, the humidity can be determined by formula or by reference to the chart or the table accompanying the instrument. In practice the reading of the dry-bulb thermometer gives the air temperature, and the difference between that reading and the reading of the separate wet-bulb thermometer gives the wet-bulb depression; both thermometers are mounted on one panel.

To obtain accuracy it is essential that the wick be clean and that there be a brisk circulation of air over the wet bulb. A velocity of at least 15 feet per second is recommended by various authorities, and this velocity is desirable for accurate readings at atmospheric temperatures. At ordinary kiln temperatures, however, sufficient accuracy can be secured with very much lower air velocities.

With certain types of wet and dry bulb thermometers circulation past the wet bulb is produced by whirling the entire instrument. Such instruments are known as sling psychrometers. (Pl. 9, B.) Other instruments are provided with maximum-reading thermometers, so that they can be removed from the kiln and read outside. The mercury or other fluid column in these thermometers must be shaken down before they are used again. They indicate only the maximum wet and dry bulb temperatures since they were last shaken down. If the temperature and humidity variations have been reasonably great during this time the readings will be misleading.

Table 1 is a humidity chart for use with wet and dry bulb thermometers. It is based on the difference between the wet-bulb and dry-bulb temperature. The dry-bulb temperatures are in the left-hand column and the differences between wet and dry bulb temperatures are in the top row. The relative humidity is given at the intersection of the row and the column. Suppose the dry bulb reads 140° F., and the wet bulb 130° F.; the difference between them is 10°. By reading across the 140 row to column 10 the relative humidity will be found to be 75 per cent.

TABLE 1.—*Relative humidity table for use with wet and dry bulb thermometers*

| Temperature of dry bulb (° F.) | Difference between wet-bulb and dry-bulb thermometers, in degrees Fahrenheit | | |

152	98	95	93	90	88	85	83	81	79	76	74	72	70	68	66	64	62	60	59	57	55	53	52	50	48	47	46	44	42	41	40	39	37	36	35	33	32	31	30	29	28	26	25	24	23	22	21	20	19	19
154	98	95	93	90	88	85	83	81	79	77	74	72	70	68	66	65	63	61	59	57	56	54	52	50	49	47	46	44	43	42	40	39	38	37	35	34	33	32	30	29	28	27	26	25	24	23	22	21	20	19
156	98	95	93	90	88	85	83	81	79	77	74	72	71	69	67	65	63	61	59	58	56	54	53	51	49	48	46	45	43	42	41	40	38	37	36	34	33	32	31	30	29	28	27	25	24	23	23	22	21	20
158	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	63	61	60	58	56	55	53	51	50	48	47	45	44	43	41	40	39	38	36	35	34	33	31	30	29	28	27	26	25	24	23	22	21	20
160	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	64	62	60	58	57	55	53	52	50	49	47	46	44	43	42	41	39	38	37	35	34	33	32	31	30	29	28	27	25	24	24	23	22	21
162	98	95	93	90	88	86	84	82	80	77	75	73	71	69	68	66	64	62	60	59	57	55	54	52	51	49	47	46	45	44	42	41	40	39	37	36	35	34	32	31	30	29	28	27	26	25	24	23	22	22
164	98	95	93	91	88	86	84	82	80	78	75	73	72	70	68	66	64	62	61	59	58	56	54	52	51	49	48	47	45	44	43	41	40	39	38	36	35	34	33	32	31	30	29	28	26	25	25	24	23	22
166	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68	66	65	63	61	59	58	56	54	53	51	50	48	47	45	44	43	42	41	39	38	37	36	35	33	32	31	30	29	28	27	26	25	24	23	23
168	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68	67	65	63	61	60	58	56	55	53	52	50	49	47	46	45	43	42	41	40	39	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23
170	98	95	93	91	89	86	84	82	80	78	76	74	72	70	69	67	65	63	62	60	59	57	55	53	52	51	49	48	47	45	44	43	41	40	39	38	37	35	34	33	32	31	30	29	28	27	26	25	24	24
172	98	95	93	91	89	86	84	82	81	78	76	74	73	71	69	67	66	64	62	60	59	57	55	54	53	51	50	48	47	46	45	43	42	41	39	38	37	36	35	34	33	32	31	30	28	27	26	26	25	24
174	98	95	93	91	89	87	84	83	81	78	76	75	73	71	69	67	66	64	62	61	59	57	56	54	55	51	50	49	47	46	45	43	42	41	40	39	37	36	35	34	33	32	31	30	29	28	27	26	25	24
176	98	96	94	91	89	87	85	83	81	79	77	75	73	71	70	68	66	64	63	61	60	58	56	55	53	52	50	49	48	46	45	44	43	42	40	39	38	37	36	35	34	33	32	31	29	28	27	27	26	25
178	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	66	64	63	61	60	58	56	55	54	52	51	49	48	47	46	44	43	42	41	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25
180	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	67	65	63	62	60	58	57	55	54	52	51	50	48	47	46	45	43	42	41	40	39	38	36	35	35	34	33	31	30	29	28	27	27	26
182	98	96	94	91	89	87	85	83	81	79	77	75	74	72	70	68	67	65	63	62	60	59	57	56	54	53	51	50	49	48	46	45	44	43	42	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26
184	98	96	94	92	89	87	85	83	82	79	77	76	74	72	70	69	67	65	64	62	61	59	57	56	55	53	52	50	49	48	47	45	44	43	42	41	39	38	37	36	35	34	33	32	31	30	29	28	27	27
186	98	96	94	92	90	87	85	83	82	80	78	76	74	72	71	69	67	66	64	62	61	59	58	56	55	53	52	51	49	48	47	46	44	43	42	41	40	39	38	37	36	35	34	33	32	30	30	29	28	27
188	98	96	94	92	90	87	85	84	82	80	78	76	74	73	71	69	68	66	64	63	62	59	58	57	55	54	52	51	50	49	47	46	45	44	43	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27
190	98	96	94	92	90	88	85	84	82	80	78	76	75	73	71	69	68	66	65	63	62	60	58	57	56	54	53	51	50	49	48	46	45	44	43	42	41	39	38	37	36	35	34	33	32	31	30	30	29	28
200	98	96	94	92	90	88	86	84	82	80	79	77	75	74	72	70	69	67	66	64	63	61	60	58	57	55	54	53	52	51	49	48	47	46	45	43	42	41	40	39	38	37	36	35	34	33	32	32	31	30
210	98	96	94	92	90	88	86	85	83	81	79	78	76	75	73	71	70	68	67	65	64	63	61	60	59	57	56	54	53	52	51	50	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	32
220	[1]98	[1]96	[1]94	[1]92	[1]91	[1]89	[1]87	[2]85	83	82	80	78	77	75	74	72	71	69	68	66	65	64	62	61	60	58	57	56	54	53	52	51	50	48	47	46	45	44	43	42	41	41	39	39	38	37	36	35	34	33

[1] Possible only at pressures higher than normal atmosphere.
[2] Superheated steam, at normal atmospheric pressure, no air present. At lower humidities air is mixed with the water vapor.

No satisfactory instrument for making a direct record of the relative humidity in a dry kiln is available, but a record of the wet-bulb and dry-bulb temperatures forms a reasonably good substitute, and is the expedient usually employed. It is obvious, of course, that such a record can be secured by the use of two separate recording thermometers, one suitably equipped with a wet wick over the bulb. It is just as obvious that a better arrangement would be to have both records on the same chart, and this is the way most humidity recorders are made. These instruments are known also as wet and dry bulb recording thermometers, recording psychrometers, and recording hygrometers. In principle humidity recorders are exactly like recording thermometers, there being two complete though component instruments in a single case. (Pls. 3 and 4.)

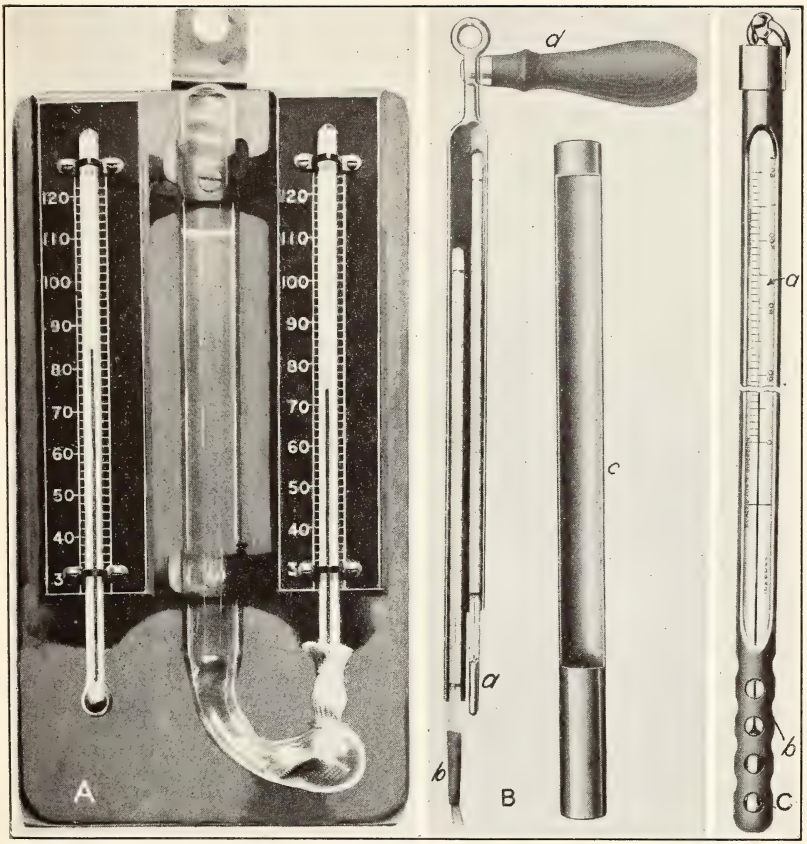
Two types of wet bulb are used in dry-kiln work, the well-known wick-and-water-trough type and the porous-sleeve type. In the latter (pl. 4, B) a porous sleeve of alundum or other suitable material, which surrounds the wet bulb, is kept filled with water. The water, gradually seeping through the porous walls, is evaporated on the sleeve surface, producing the necessary depression of temperature in the sleeve and the contained bulb. Both types are thoroughly reliable and are fully satisfactory under proper operating conditions. Hard water soon clogs up the porous sleeves, just as it encrusts the wicks, but the sleeves can be cleaned very easily by immersing them in muriatic (hydrochloric) acid, and the wicks can be changed at slight trouble and expense.

CONTROL OF KILN HUMIDITY

The humidity within a kiln may be raised or lowered in two ways: (1) Water vapor may be directly added to or removed from the kiln atmosphere or (2) part of the air may be removed from the kiln and may be replaced by wetter or by drier air from the outside. To some extent both of these processes are continuously going on in the ordinary dry kiln, and it is not possible to exercise full control over certain parts of them. Thus, the evaporation of water from the wood is continuously adding water vapor to the kiln atmosphere, and air leakage into and out of the kiln is continuously tending to lower the humidity, since outside air almost invariably has a lower absolute humidity than kiln air. When air of a given absolute humidity is warmed, its relative humidity decreases, since its capacity for moisture increases, and the same weight of water vapor then represents a smaller percentage of its total capacity for moisture.

DEW POINT

A controllable method for removal of moisture from the kiln depends upon the dew point of the kiln atmosphere. The temperature at which any atmosphere, upon cooling, becomes saturated is known as the dew-point temperature. This temperature is a fixed, determinate one for any given set of conditions. Ordinarily it is somewhat lower than the wet-bulb temperature, with which it must not be confused; at saturation, however, the dew-point temperature, the wet-bulb temperature, and the dry-bulb temperature are all equal.

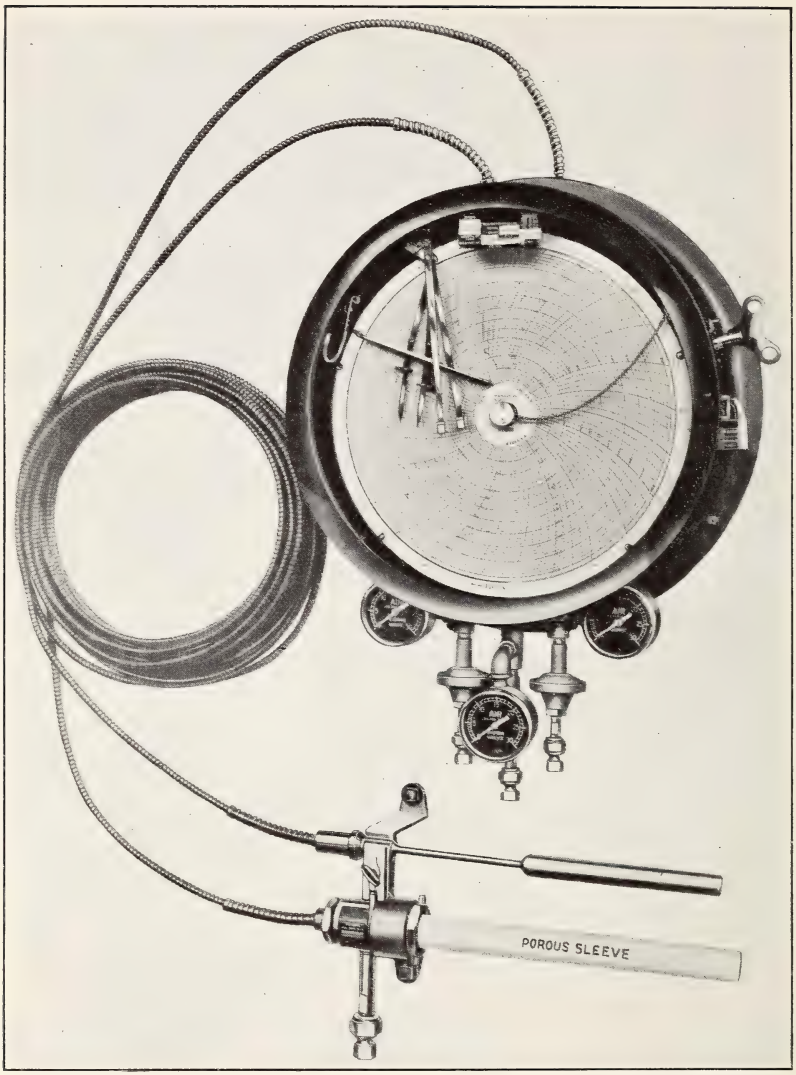


GLASS-STEM INDICATING INSTRUMENTS

A.—Wet and dry bulb hygrometer, the common form of this type of instrument. The right-hand thermometer is ordinarily the one used as a wet bulb, though either one can be so used. The central reservoir, which is readily detachable, must be filled with water, preferably soft or distilled, often enough to keep the wick fully moist at all times. Accurate readings require a brisk circulation of air past the wet bulb; this is usually secured, in the absence of natural circulation, by vigorous fanning.

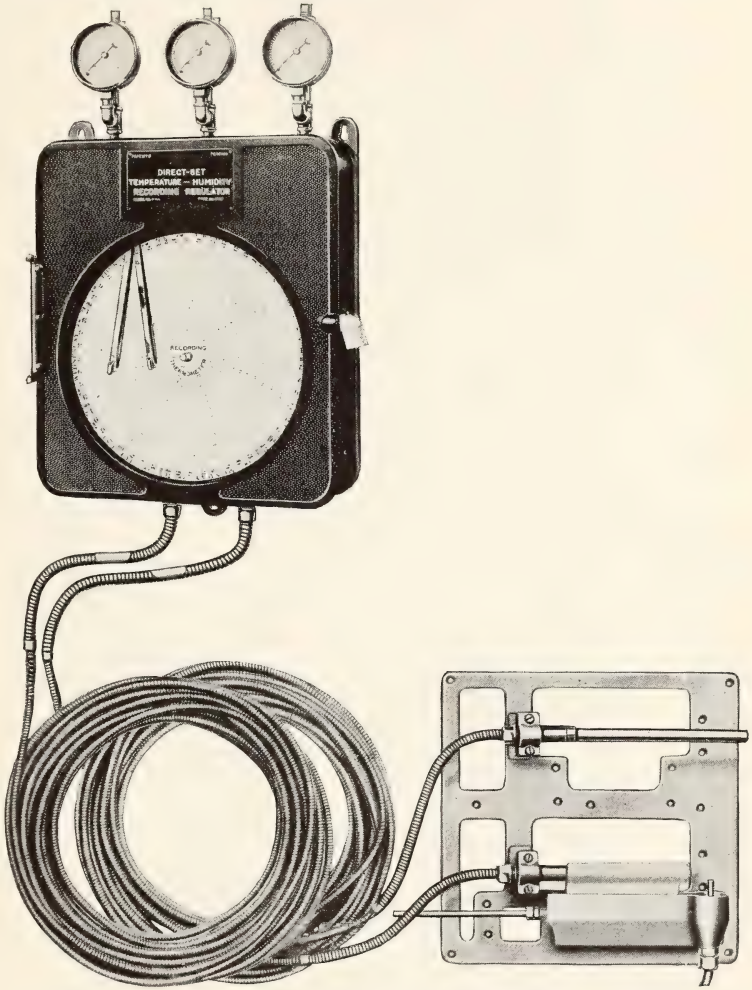
B.—Sling psychrometer. This instrument is a form of wet and dry bulb hygrometer. The air circulation needed to procure evaporation from the wet wick *b* is secured by whirling the entire instrument around the handle *d;* the metal sleeve *c* protects both the dry bulb *a* and the wet bulb. The sling psychrometer is convenient for use at the normal atmospheric temperatures of shops and storerooms, but has not found favor in dry kilns.

C.—Etched-stem chemical thermometer *a* with metal protecting sleeve *b*. This type makes a very satisfactory standard for the calibration of indicating and recording thermometers and hygrometers.



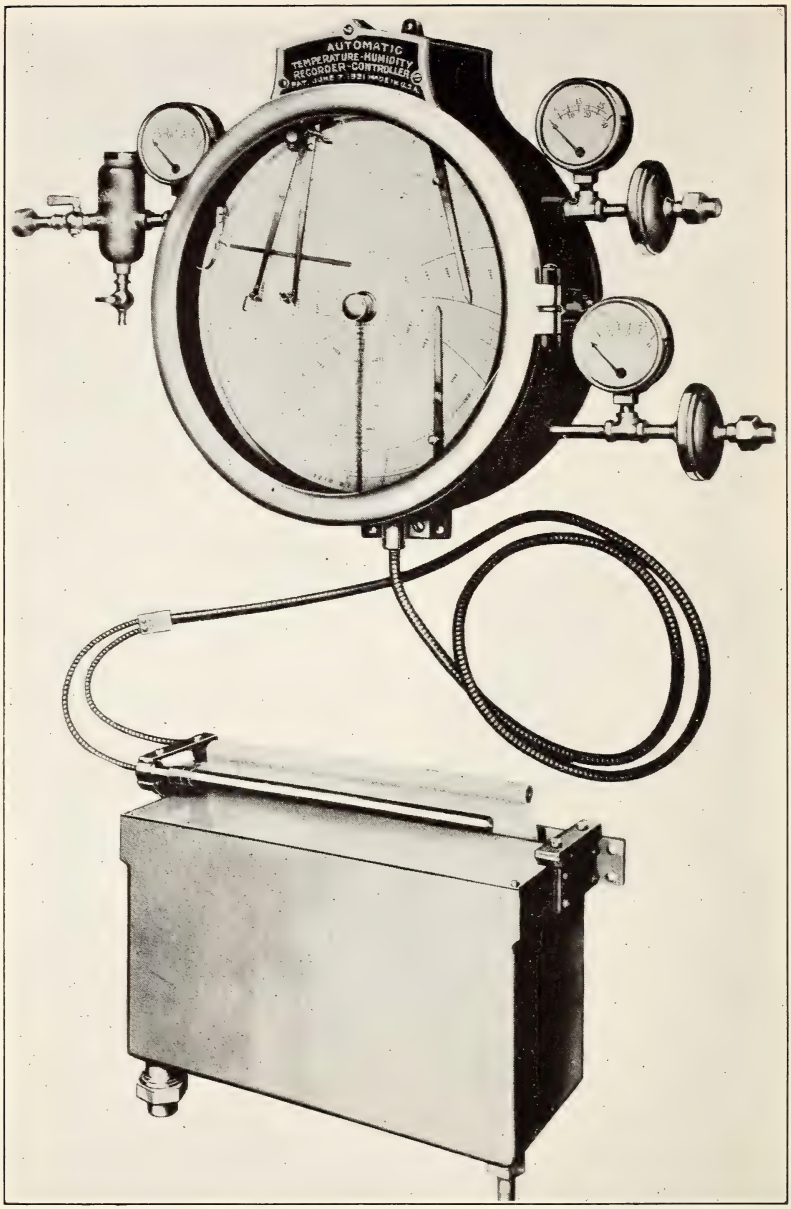
AIR-OPERATED EXTENSION-TUBE RECORDER CONTROLLER WITH A POROUS-SLEEVE TYPE WET BULB

As the name implies, recorder controllers perform two separate functions; one is to record temperature, and the other is to control it. The instrument illustrated is of the double type, being equipped with two entirely separate recording and controlling mechanisms; both records, however, are made on the same chart. When arranged as shown here, with a wet bulb and a dry bulb close together, the instrument functions as a temperature and humidity recorder and controller, and is named "humidity recorder controller" by the maker. Since the two operating systems are independent, it would be quite possible to use them for entirely unrelated purposes. The instrument is set by moving the two pointers, at the left of the two pens, to the desired temperatures, as indicated on the chart. When the instrument is functioning and the temperatures are under control, the pens ride directly over their respective pointers. The adjustment of the pointers is made from outside the case, by turning the winding key at the right of the case, directly over the padlock.



AN AIR-OPERATED EXTENSION-TUBE RECORDER CONTROLLER WITH A WATER BOX

This instrument has the same functions as the one illustrated in Plate 10, although it is equipped with a wet wick and water box, whereas the other one has a porous sleeve. Either style of wet bulb may be had with any of the recorder controllers on the market. The two pointers by means of which the instrument is set are shown directly beneath their respective pens, which is the normal operating position.



AN AIR-OPERATED EXTENSION-TUBE RECORDER CONTROLLER WITH THE EXTENSION TUBES IN SINGLE ARMOR

The functions of this instrument are the same as those of the instruments illustrated in Plates 10 and 11. Its general appearance is somewhat different, however, because the two pointers by means of which it is set are on the right side of the chart, whereas the pens are on the left side. When double-pen recorders and recorder controllers are to be used for wet and dry bulb record and control, it is usual to inclose the two extension tubes in a single armor, as shown here. When this is done, it is obviously impossible to separate the bulbs more than a foot or so, and therefore they can not be used independently of each other. This restriction is, in general, of little importance. All of the instruments illustrated can be furnished in either style.

CONDENSERS

Water vapor may be removed from the kiln atmosphere by condensation, since it condenses as it passes over a substance colder than the dew point. Pipes with cold water flowing through them are commonly used for condensing. When cold water is not available, a refrigeration plant may be installed, with brine circulating through the condenser pipes.

WATER SPRAYS

Water sprays may be used either to raise the humidity within the kiln or to lower it; the result depends upon relative temperatures and upon the method of application. The spraying of water directly into the kiln atmosphere, in such manner that it can be evaporated for absorption by this atmosphere, will raise the kiln humidity. To lower the humidity with water sprays, it is necessary (1) to pass part or all of the air in the kiln through water sprays cold enough to cool the air below its original dew point, thus actually condensing moisture out of it, (2) to separate the spray water and condensed moisture from the air, and (3) to reheat the air to the kiln temperature and return it to the kiln.

COMMON PRACTICE

In the chemical laboratory air is dried by passing it through chemicals that have affinity for moisture, principally calcium chloride and sulphuric acid. The process has not been developed for commercial wood drying. In actual practice, most dry kilns depend upon leakage and ventilation to lower the humidity and upon steam jets to raise it as required.

WET-BULB CONTROLLERS

The control of humidity is more difficult than temperature control, and greater attention must be given to the humidity-regulating apparatus in order to secure satisfactory results. One principal reason is that a small difference in the wet-bulb temperature produces a comparatively large difference in humidity, so that securing good control requires an accurate instrument.

The humidity controllers of greatest importance in kiln drying are those that depend upon a wet-bulb of one type or another. Temperature controllers of various types can be made into wet-bulb humidity controllers by providing the bulb, the temperature-sensitive element, with a suitable wick and a water supply. Wet-bulb control on dry kilns is generally carried out by means of air-operated instruments. Self-contained thermostats can also be used for this purpose, particularly under conditions that do not require the greatest accuracy and quickness of response to changes in temperature. Wet-bulb controllers, however, can keep only the wet-bulb temperature constant. If the dry-bulb temperature is also kept constant, the humidity will remain constant. If it is not, the humidity will vary, even if the wet-bulb temperature is accurately controlled. It is obvious, therefore, that the wet-bulb controller alone can not keep the humidity constant, and that some form of temperature (dry-bulb) control must be used in conjunction with it. It also is

obvious that if either instrument fails to function, humidity control will also fail. Several instruments have been developed to overcome this inherent defect. In one type the operation of the controller depends upon the difference in pressure between a dry-bulb system and a wet-bulb system, both incorporated in the same instrument, and in another type changes in the weight of a hygroscopic material, such as wood shavings, operate the controller.

STEAM JETS

Humidity controllers almost without exception operate valves controlling steam jets, just as temperature controllers operate valves in the heating system, and the same kind of valves are ordinarily used, each one being adapted to the needs of the particular service it is to render. Since the use of humidity controllers on steam-jet lines presupposes the necessity of always increasing the humidity, means must be provided to insure this need. Ordinarily in natural-circulation kilns the fresh-air inlets and the moist-air vents are open sufficiently to require humidification of the kiln atmosphere. If necessary in special cases, the controllers can be made to operate dampers of various sorts and also to regulate the flow of water in condenser pipes. Humidity control in the various kiln types will be considered more in detail later.

SPECIAL CONTROLLERS

Several special types of temperature and humidity control instruments have been either designed or adapted for dry-kiln use. Principal among them are the humidity recorder-controllers (pls. 10, 11, and 12), which are generally of the air-operated direct-set type and combine, in a single case, two recording thermometers and two temperature controllers. Only two tube systems are required, a wet-bulb system and a dry-bulb system. Each tube system operates its individual recorder pen and its own air valve. The instrument serves to control temperature and humidity and to record both the wet-bulb and the dry-bulb temperature, and obviates the need for other recorders or controllers on the kiln. Air-operated humidity controllers, without recorders, which combine two single controllers in one case, are suitable for use where temperature records are not desired or where they are secured by recording thermometers.

Several special forms of humidity controllers have been developed for special kinds of drying schedules. One of these controllers, operated by the rise and fall of the humidity in the kiln, produces periodic oscillations of humidity between predetermined limits. Another, operated by clockwork, serves to steam the kiln charge at set intervals; the time between steamings and the length of the steaming period are adjustable.

AIR CIRCULATION IN THE KILN

Air circulation performs several important functions in kiln drying. It serves to bring the heat to the lumber and to carry away the evaporated moisture. Upon its briskness and uniformity depends, to large degree, the uniformity of temperature and of

humidity throughout the kiln. Circulation, as applied to dry kilns, may be divided into two general kinds, recirculation and outside circulation. Recirculation, which uses heated air over and over, takes place entirely within the kiln and the recirculating ducts outside of the kiln, if there are any; in outside circulation, fresh, cold air enters the kiln from the outside and passes through it, exhausting to the outside. Although most kilns have at least a little circulation of each kind, the recirculation is far greater in volume and hence is much more important, in practically all types, than the outside circulation. Progressive blower kilns, in which the entire volume of air handled by the blowers is drawn from the outside at one end of the kiln and is discharged to the outside from the other end, are an exception to this rule; however, very few lumber dry kilns of this type are in operation.

PRODUCTION OF CIRCULATION

Circulation in dry kilns is produced in several different ways. For present purposes these ways may be divided into three groups, as follows: (1) Differences in temperature, (2) mechanical means, and (3) combinations of 1 and 2.

Differences in temperature are secured by three distinct means: (1) Through evaporation of moisture, (2) by heating the kiln above the temperature of the surrounding atmosphere, and (3) by the use of heating elements and of cooling elements properly placed.

Recirculation of air caused by evaporation is of extreme importance in kiln drying, and every effort should be made to take full advantage of it. As already pointed out, evaporation of moisture results in cooling of the air. The cooled air tends to sink, and warm air from the heating coils tends to rise to replace it. If this movement is facilitated, through proper arrangement of the lumber and of the heating coils, a very definite circulation will be set up and will maintain itself as long as heat is supplied and evaporation takes place. Much of the recent improvement in dry kilns of the natural-circulation type has resulted from taking advantage of such recirculation.

Under normal conditions, the dry kiln is hotter than the surrounding atmosphere. Further, the warm air in the kiln is lighter than the air outside and hence is continually escaping through the top; cold outside air consequently is drawn in at the bottom. There is always inleakage at the bottom and outleakage at the top of a kiln, no matter how well it may be built, and when movement of the air is made easy by providing outlet flues and fresh-air intakes the circulation becomes quite brisk; the velocity in the flues may then be 600 feet or more per minute, depending upon circumstances. A reasonable amount of draft may be secured by means of the outlets, even though no air-intake openings are provided. Similarly the draft secured through the intakes may also be considerable even when there are no vents, or when the flue dampers are closed. Under such conditions the whole kiln acts as a chimney, and the leakage is sufficient to permit the escape and the replacement of appreciable amounts of air.

Air intakes are usually placed at the bottom of the kiln and the outlets from the kiln to the flues at varying heights along the sides

and in the ceiling. The flues usually, but not always, project above the roof.

The circulation produced by a flue is outside circulation; its principal effect, an important matter, is to lower the humidity within the kiln. Because its volume is comparatively small, however, its effect upon the internal circulation is not of great importance in the average kiln. It is sometimes stimulated by the use of heater coils in the flues, which increase the temperature difference between the air in the flue and that outside the kiln, thus making the warm air move upward faster.

As already suggested, if air is being continuously heated at one point in a confined space and is being cooled similarly at another point, there will be a continuous flow of heated air upward at the first point and of cooled air downward at the second point. Cross circulation between the two points will also occur, the warmed air at its high level flowing from the hot point to the cold one and cold air below flowing in the reverse direction. Condensers may well act as the cooling agents and the steam coils as the heat suppliers in such a circulation system. If the pipes of the condensers are cold enough, moisture can be condensed out of the kiln air, and the humidity thus lowered.

Mechanical means for producing circulation in dry kilns may be divided into two groups, namely, (1) fans and (2) steam jets.

The fan group divides itself logically into two classes: Centrifugal blowers and disk fans. Centrifugal blowers used in dry kilns are almost all of the multiple-vaned rotor type. They are most often driven by electric motor, either direct or from a line shaft. Their application is now limited almost entirely to compartment kilns, principally for producing recirculation. A small amount of outside circulation is usually provided for by means of a duct from the outside to the suction side of the fan. Centrifugal blowers are almost invariably located outside of the kiln.

Disk fans find various applications in dry-kiln work. In one of them, one or two fans, mounted in the end wall, draw the air lengthwise through the kiln, bringing about a longitudinal circulation. Sometimes the air is discharged to the outside atmosphere, and sometimes it is returned to the opposite end of the kiln, often through an outside duct, and recirculated. Fans of this kind are usually quite large in diameter and, as a rule, are belt or chain driven by electric motors.

Another application is the internal-fan kiln. In this case, a number of disk fans are mounted upon a single shaft which runs longitudinally through the kiln and is driven, usually by an electric motor, from the outside. These fans are so housed that they effect a cross circulation within the kiln. Reversal of the direction of rotation of the shaft causes reversal in the direction of the circulation.

Fans of either the disk or the centrifugal type, properly designed and installed, are capable of producing very high rates of circulation.

Steam jets and steam-jet blowers, of one sort or another, are used in the majority of dry kilns. Their principal purposes are to assist in producing circulation and to increase the humidity. Both objects, of course, can be accomplished simultaneously. In fact, except when the jets form aspirators in the uptake flues, they necessarily increase the humidity.

The most important use of steam jets, as aids in producing circulation, is in kilns that lack other means of forcing circulation. While they are commonly so placed as to stimulate recirculation within the kiln, they are occasionally located in the intake flues or in the outlets to augment the outside circulation. A usual arrangement of them is in rows along the sides or down the center of the kiln. The mechanical efficiency of steam jets is very low in comparison to that of fans or blowers, but other considerations often outweigh this fact.

Water sprays, as used in the water-spray kiln, produce circulation (assisted by the heating coils) through a combination of temperature difference and of mechanical means. Located in rows along the sides or in the center of the kiln, near the bottom and pointing downwards, they both cool the air and drive it downward by impact. It passes over the heating coils after leaving the sprays, then through the lumber, and again through the sprays.

MEASUREMENT AND CONTROL OF CIRCULATION

Although the temperature and the humidity best for a particular drying condition may be specified with certainty, the amount of circulation desirable is not so easily disposed of. While rapid, uniform circulation does induce faster and more uniform drying and also permits better control of the drying conditions than slow, irregular circulation, it becomes increasingly difficult to secure uniformity as the speed of circulation rises, beyond certain limits, and producing and maintaining high circulation rates add to the cost of operation. Economic considerations naturally make desirable the range in rates of circulation that yields the greatest return on the total investment.

RATE OF CIRCULATION

Prescribing one specific rate of circulation as the best for all drying conditions is impossible, because circulation requirements vary widely; considerable difference in them may exist even during a single kiln run. A number of detail factors have an influence in determining the rate of circulation proper for any particular set of conditions; among the most important are the following: (1) Species of wood, (2) grade of lumber, (3) previous seasoning of lumber, (4) size of lumber, (5) purpose for which lumber is to be used, and (6) length of air travel through lumber pile. These factors of course have an important bearing upon the selection of the drying schedule for the problem in hand. Rapid rates of circulation and high-humidity drying schedules have proved themselves to be paying investments in drying both green hardwoods and green softwoods. One of the outstanding developments in seasoning practice within the last four years has been the progress made in the use of high-circulation rates in the drying of certain southern and western softwoods. Rates as high as 150 feet per minute through the lumber charge are not unusual. Rapidly drying softwoods having large amounts of moisture when green require a circulation of about 100 to 150 feet per minute through the lumber stacks with a length of air travel not over 5 to 7 feet if the most effective drying schedules are to be employed successfully and if the kiln degrade is to be kept to a minimum. Green hardwoods, which as a rule dry more slowly than soft-

woods, usually do not require a circulation greater than 25 feet per minute for a 5-foot air travel, and previously air-dried hardwoods require still less circulation.

TESTING THE CIRCULATION

Much trouble in drying is caused by insufficient or nonuniform circulation, and frequently determining the amount of circulation and its direction is a necessary preliminary to prescribing a remedy. The rate of circulation inside the average kiln is so low that most of the methods usually employed in the measurement of air velocities are not suitable. Although the velocity of the air occasionally is great enough to permit the successful use of strips of tissue paper to show its direction and intensity, about the only method that has proved universally satisfactory is to watch the drift of smoke and, if desired, to time its movement over a known distance by means of a stop watch. One of the special advantages of this method is that it

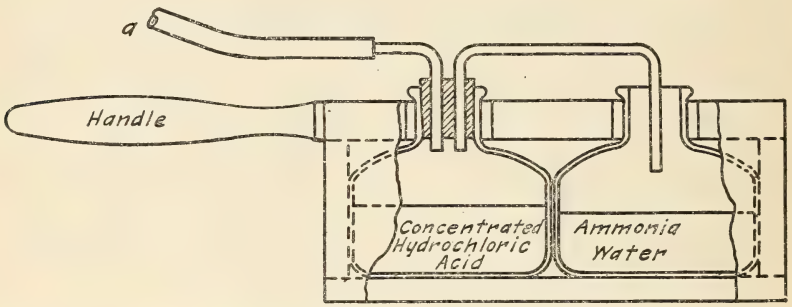


FIGURE 5.—A smoke machine for testing the air circulation in dry kilns. The bottles are common ink bottles—almost any kind of a bottle will do, but in order to avoid bulkiness a comparatively narrow one is desirable. The box and its handle can be constructed in any way desired, or in case of need could even be dispensed with entirely. Two pieces of bent-glass tubing, a cork, and a rubber tube *a* complete the machine; short lengths of glass and of rubber tubing may be used instead of the bent glass, although they are not so good. The tube *a* should be long enough to allow the operator to extend the apparatus at arm's length while blowing into the tube. Some operators prefer to fit the end of the rubber tube with a syringe bulb; this is practically necessary when a mask is worn

shows clearly the direction of movement. It has also some disadvantages. Smoke from any burning substance, for instance, tends to rise because of its higher temperature; hence the true circulation will not be indicated until the smoke has cooled to the temperature of the surrounding air. The operator, of course, must be inside the kiln during the test, and it is essential that all the doors be closed and that the kiln be operating in the normal manner.

Tobacco, punk sticks, or rope may be used to provide the smoke, although it is difficult with these means to get a suffcient volume, and the fire risk is an objectionable feature. A special form of fireless smoke machine for dry-kiln work has been developed at the forest products laboratory. It consists essentially of two small bottles and a few pieces of connecting tubing. One bottle is partly filled with concentrated hydrochloric acid and the other with strong ammonia water. When air is blown through the bottles, fumes of the two chemicals are mixed, producing a dense fog or smoke that will drift readily with the air current. (Fig. 5.)

For velocities higher than the average, such as those usually occurring in the flues of natural-circulation kilns and in the interiors of some forced-circulation types, the Biram type of anemometer is suitable. This anemometer is in essence a disk fan mounted upon pivot bearings and provided with a revolution counter. The counter is ordinarily in the form of a dial and pointer, one revolution of the pointer usually representing an air movement of 100 feet. A watch is necessary to determine the time corresponding to a certain air movement. It is customary to let the anemometer run a definite number of minutes, and then to divide the number of feet recorded by the number of minutes, the quotient being the velocity expressed in feet per minute. Since the velocity in any duct varies throughout the cross section, commonly being greatest at the center and least along the sides, a single reading will probably fail to represent a true average, and for accurate results the cross section of the duct should therefore be divided into squares about equal to the diameter of the anemometer, and a reading taken on each square. This will seldom be necessary, however, in ordinary work. In using anemometers in open places especial care must be exercised to set the anemometer with its axis truly parallel with the air movement, because otherwise it will register less than it should. Smoke may be used to indicate the direction of the air movement.

Anemometers are imperfect in that the speed of the fan is not truly proportional to the air velocity over the entire range of usefulness of the instrument, and a correction factor accordingly is necessary. This correction factor is determined at the factory by actual trial, and a calibration curve showing the amount of correction to be applied at different velocities should accompany the instrument.

DRYING AND DRYING STRESSES

MOISTURE GRADIENT

The moisture in wood tends to distribute itself equally by flowing from spots of high moisture content to those of low. If it is desired to produce a flow of moisture in a piece of wood of uniform moisture content the uniform condition must first be upset. This may be done by removing some of the moisture from the surface by circulating air of proper temperature and humidity around the piece. As soon as evaporation from the surface commences, a "moisture gradient" is established, that is, the wood has then been made drier on the surface than in the interior, and thereby a movement of the moisture from the interior toward the surface has been started.

A moisture gradient is usually thought of as a curve. Figure 6 shows some possible moisture gradients in a wood block of substantial size. The full line, A, represents a typical variation in internal moisture conditions when the surface of the green wood has just been dried to equilibrium with the temperature and the humidity of the surrounding atmosphere. The horizontal distances between the vertical axis (at the left) and points on the curve represent distances measured directly inward from the surface of the block. Similarly the vertical distances between the horizontal axis (at the bottom) and these same points on the curve represent the corresponding values of the moisture content at the points.

The lower dotted line, C, presents a typical moisture gradient for almost-oven-dry conditions in the interior of the block and for a surface equilibrium value lower than that of A. The nearly uniform moisture content makes curve C much flatter than the steep A, that is, the slope of C is much less than that of the steep part of A.

The intermediate dotted line, B, follows moisture conditions intermediate to those of A and C.

Besides changing with the temperature and the humidity of the surrounding air, the moisture gradient is affected by a number of

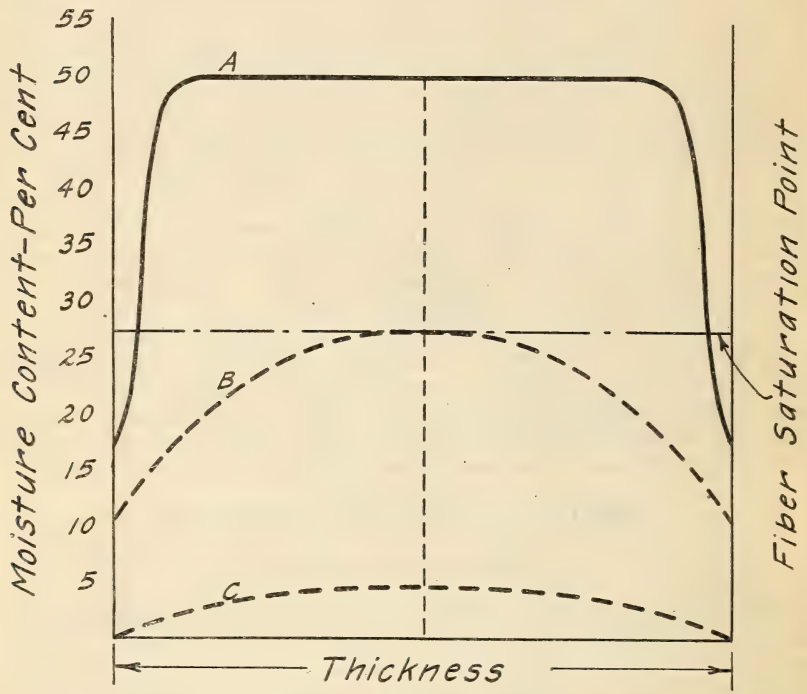
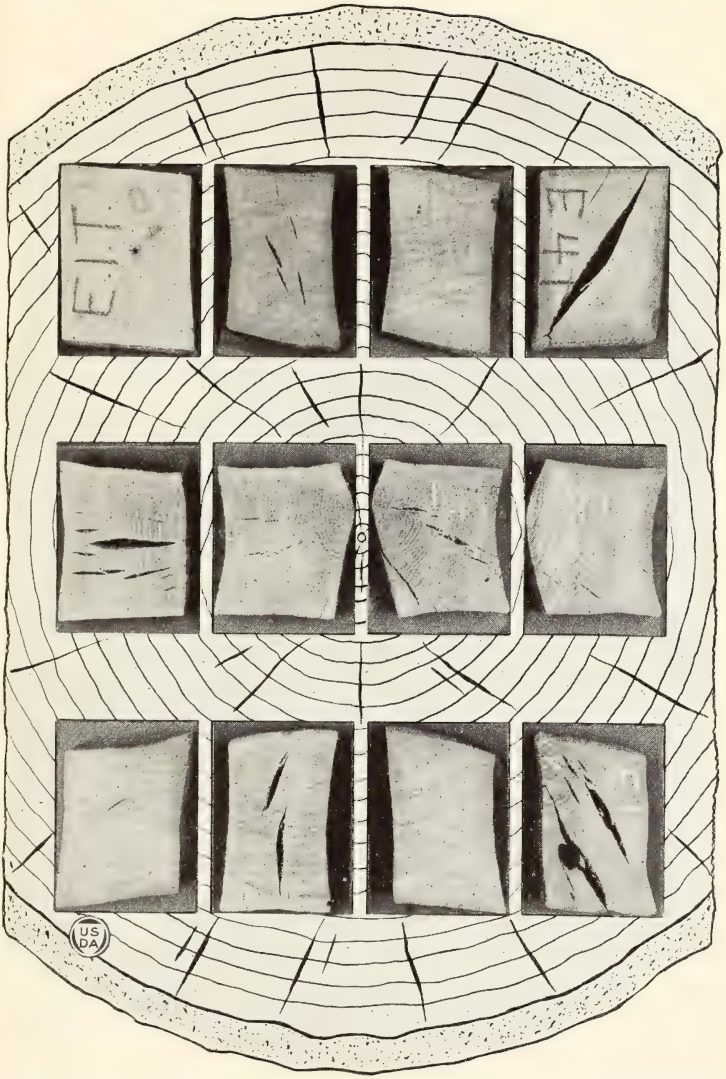


FIGURE 6.—Typical moisture gradients, across the thickness of a board, at three stages of drying. Curve A is intended to represent the moisture gradient just after the drying has commenced. The moisture content in the center of the piece then is still very high, but that at the surface has reached equilibrium with the surrounding atmosphere. Curve B illustrates an intermediate stage, when the center of the piece has just reached the fiber-saturation point. Curve C shows an extremely dry condition, in which the surface has reached zero moisture content

internal factors, such as the amount and the distribution of the moisture in the wood, the size of the piece, and its structural characteristics. Moisture gradients, therefore, are likely to be constantly changing. In fact, if dry wood is placed in an extremely moist atmosphere, the zero-thickness end of the curve will become the highest point on it, the reverse of the situation shown in the figure.

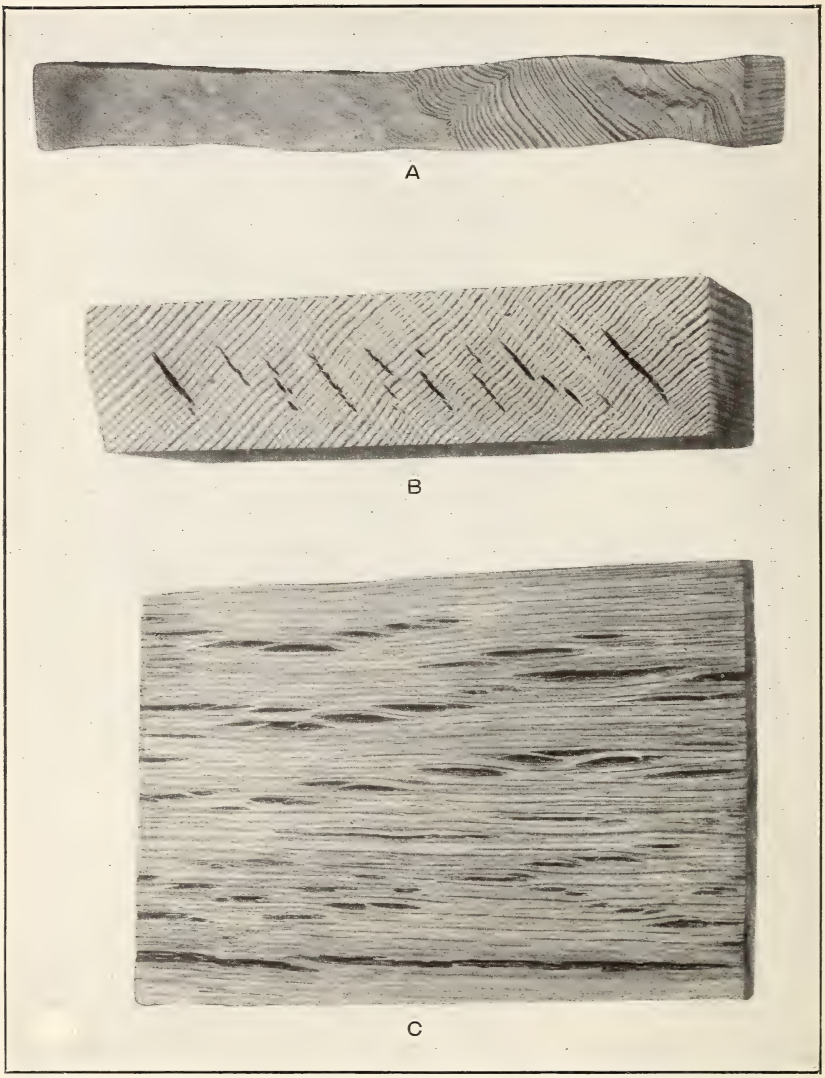
SHRINKAGE

In discussing the shrinkage of wood during drying and the resulting internal stresses, together with the moisture gradient, it is convenient to think of a piece of wood, especially a stress sec-



CROSS SECTION OF A SOUTHERN SWAMP OAK TREE CUT INTO BOLSTER STOCK AND DRIED

The black rectangles represent the green size and the exact location of the pieces in the tree. The dried pieces exhibit in exaggerated form many of the common drying defects, such as checks, honeycomb, diamonding, and even cupping. The difference between radial and tangential shrinkage and the comparatively small shrinkage of some of the sapwood are illustrated.



TWO IMPORTANT KINDS OF DRYING DEFECTS

A.—Collapse in redwood; before drying, the board of which this piece is a section was uniform in thickness. B.—Honeycomb in a cross section of a Douglas fir plank. C.—Extreme honeycomb in the tangential face of a resawed piece of plain-sawed oak.

tion, as made up of a number of layers, like the leaves of a book. The outside layers, that is, the covers, may be termed a shell, but in the following discussion all of them will be called layers.

As the drying of green wood progresses the amount of free water in the cells gradually diminishes, and soon those near the surface lose all their free water, that is, they reach the fiber-saturation point. It is at this point, which is a very definite one for most species, usually between 25 and 30 per cent moisture content, that the changes in the properties of the wood caused by drying begin to take place. As wood dries beyond its fiber-saturation point it starts to shrink and it will continue to shrink as long as it loses moisture. In fact, the amount of shrinkage is very nearly proportional to the degree of drying below the fiber-saturation point. When the moisture gradient is steep, however, the surface layers may be well below the fiber-saturation point even though the average moisture content may still be far above it, and the consequent tendency of the inclosing outer layers to contract may cause some shrinkage of the entire piece to take place. So it often happens, on account of such a moisture condition, that shrinkage throughout the piece commences while the average moisture content is still above the fiber-saturation point.

Wood is not a homogenous material, and many of its properties are different along different axes (in different structural directions). Shrinkage is one of these properties. Longitudinal shrinkage (parallel to the length of a board) is practically nothing for most species and can be neglected in most drying problems, although cross-grained stock often shrinks appreciably in a lengthwise direction on account of the longitudinal components of the tangential and the radial shrinkages. The shrinkage is more or less proportional to the density (the unit weight) of the wood; the heavier woods, as a rule, shrink more than the lighter ones.

Below the fiber-saturation point, drying is accompanied by a hardening of the wood and a reduction in its plasticity. There are also important changes in its mechanical properties; the wood becomes stronger under such stresses as bending, tension, and compression, and also gains in stiffness. The increase in these properties as the wood is dried from the fiber-saturation point to zero moisture content varies somewhat; for compression it may be more than 100 per cent of the values in the green wood. On the other hand, a few of the mechanical properties, especially those having to do with resistance to suddenly applied loads, remain practically constant as the wood dries.

DRYING DEFECTS CAUSED BY UNEVEN SHRINKAGE

Most of the defects ordinarily classed as drying defects would not exist if uneven shrinkage and the attendant stresses set up by it could be eliminated. Take, for example, the simplest case, a hypothetical one, in which boards dry without moisture gradient and with uniform radial and tangential shrinkage. If the boards are truly radial (quarter-sawed or edge-grain) or truly tangential (plain-sawed or flat-grain), they will remain flat in drying but, assuming that all were of the same width and thickness when green, after drying the radial boards will be both thinner and wider than

the tangential ones. If, however, a board is neither radial nor tangential, the difference between radial and tangential shrinkage will cause "diamonding"; its pairs of adjacent sides and edges then will no longer be at right angles to each other. (Pl. 13.) The normal curvature of the annual rings makes it impossible to find boards that are truly radial or truly tangential; in ordinary sawmill operation a large number are cut in which the rings are tangential at the center of the end section and are at an angle of from 30° to 45° to the broad faces at the edges. In boards of this kind, the difference between radial and tangential shrinkage causes cupping; the edges of the board turn away from the heart of the log, flattening out the curvature of the annual rings.

CASEHARDENING

Above the fiber-saturation point, changes in the moisture content do not produce changes in the dimensions of the wood. Below this point, loss in moisture causes shrinkage and gain causes swelling. When a moisture gradient passes through the fiber-saturation point, that is, when part of the piece is above the fiber-saturation point and part below, unrestrained shrinkage is impossible and consequently shrinkage stresses are set up in drying. Similarly when the slope of a moisture gradient, below the fiber-saturation point, is changed, stresses are set up by the nonuniform shrinking or swelling that takes place.

As already suggested, when surface layers of a board that is drying pass the fiber-saturation point they tend to shrink. In order to succeed, however, they must squeeze together all of the green wood inside, since it has not yet reached the fiber-saturation point and is therefore not ready to shrink of its own accord. The first result is that the outer layers, in trying to squeeze the core of such a board, create in it a state of compression and in themselves a corresponding state of tension. Consider, in illustration, a rubber band pulling together a bundle of papers. The band is stretched, and the papers are compressed. The only difference between the surface wood and the rubber is that the tension is put into the rubber by actually stretching it, whereas the tension is produced in the outer layers of the wood by preventing them from shrinking. The same thing occurs if a piece of wet leather is kept from shrinking as it dries.

If a piece of wood has been dried under such restraint that a tension stress has been caused in it, and if the restraint is then removed, the wood will spontaneously contract enough to relieve the stress. However, it will not shrink so much as it would have done if it had been free to shrink during the drying, even though the contraction that does occur may be sufficient to relieve the stress entirely. Such wood has acquired a tension set. Similarly, when a piece of wood below the fiber-saturation point is made to absorb moisture but is not permitted to swell, it will acquire a compression set and although when the restraint is removed it will spontaneously swell somewhat, the amount of expansion will not be so great as that which would have occurred if the piece had been allowed to swell without restraint in the first place. Further, if dried again, this time without restraint, it will shrink to dimensions smaller than the original dry

size. Wood seldom either shrinks or swells without some restraint, and therefore set is of great importance in practically all drying.

The extreme outer layers of any piece of wood of commercial size approach equilibrium moisture content shortly after drying commences. They are then in a state of tension, with a certain amount of tension set present. As the wood continues to dry, more and more of the deeper layers reach the fiber saturation point and start to shrink, thus first relieving themselves of any compression under which they may have been and afterward putting themselves in tension and as a result increasing, to a corresponding amount, the compression on the core. The entire piece shrinks, the core, which is still wet and plastic, yielding under the stress. The outer layers, now dry and quite stiff, assist in producing the shrinkage until they have relieved themselves of their tension stress. At this point of stress-freedom they set, because of the initial tension still in a condition of expansion somewhat beyond that which otherwise would be their then natural state. As the drying and the shrinking continue these outer layers become compressed, in contrast to their former condition of tension, and strongly resist further shrinkage. Accordingly the core, which is now below the fiber-saturation point and is trying to shrink, is put in tension. All of the wood in such a piece is under tension during part or most of its drying below the fiber-saturation point and each layer sets in a more or less expanded condition. When the wood is finally uniformly dry, the outer layers in consequence are in compression and the core is in tension. Under these circumstances the wood is said to be casehardened. Casehardening is of importance in most hardwoods and in many softwoods. Methods for relieving it will be considered later.

CHECKING AND HONEYCOMBING

It was assumed in the preceding discussion that the stresses in a casehardened board are insufficient to cause visible damage. If, however, the strength of the wood in tension across the grain is not great enough to resist the tensile stresses in the surface layers during the early stages of drying, they will tear open, forming surface checks of varying size and depth. (Pl. 13.) Likewise, if the inner layers are not strong enough to resist the tension placed upon them during the latter stages, they will rupture, causing honeycomb. (Pl. 14, B and C.) Both because radial shrinkage is less than tangential and because weakness occurs throughout the planes where rays and fibers cross, checks and honeycomb more often run radially than tangentially. It not infrequently happens that surface checks formed during the early stages of drying or, in the case of partially air-dried stock, before entering the kiln, close up and disappear during the final drying. In fact, the effect of shrinkage of the core may go still farther and result not only in closing the checks at the surface, but in actually deepening them and opening them up in the center of the piece of wood, thus again forming honeycomb. (Fig. 7.)

WARPING, LOOSENING OF KNOTS, END CHECKING

Uneven shrinkage results in several other drying defects, such as bowing and twisting, which are often caused by either spiral or interlocked grain, by a difference in longitudinal shrinkage between

sapwood and heartwood, and by various other irregularities in structure and in drying. (Pl. 13.) Loosening of knots is caused by the drying-out or the exudation of cementing resins and gums with dead knots, and with live knots by the differences in shrinkage resulting from the right-angle relation of the axes of the knot and of the tree—the axis of the knot coincides with that of its branch. The knot shrinks away from the rest of the wood lengthwise of the board, but does not do so appreciably in the crosswise direction. End checking, which is caused by the excessively rapid drying of the end surfaces, is discussed more fully under "Drying schedules."

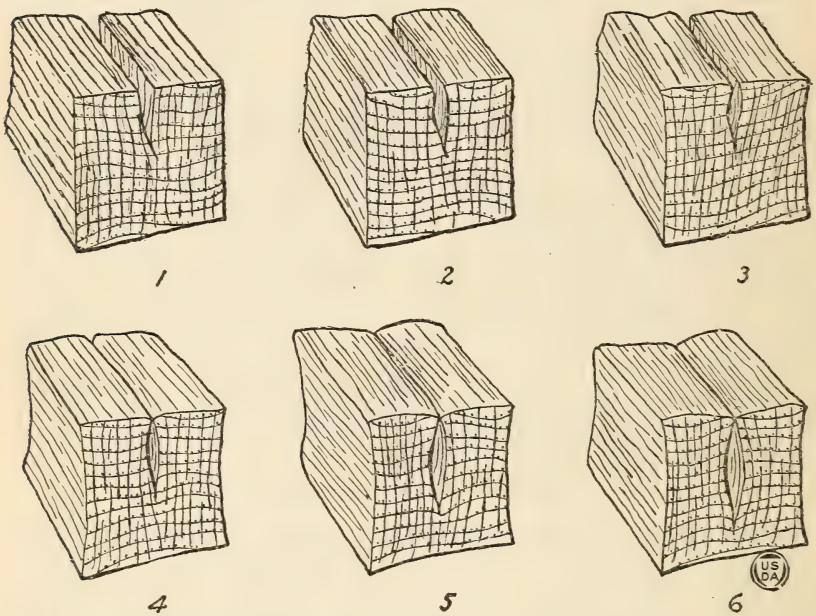


FIGURE 7.—Development of a surface check into a honeycomb. In stages 1, 2, and 3 the check is gradually closing as the center of the piece shrinks in drying. Stages 4, 5, and 6 show how the tensile stresses deepen the honeycomb as the casehardening becomes more severe. The depression above the honeycomb in stages 5 and 6 is typical

COLLAPSE

One form of seasoning defect is the actual collapse of rows of cells, just as a rubber tire collapses when the air is let out. (Pl. 14, A.) This defect occurs principally in the heartwood of only a few species, such as redwood, western red cedar, cypress, swamp-grown oaks, and red gum, although it is occasionally seen in other species, such as hickory and black walnut. No entirely successful method of avoiding it has been developed. The establishment of a steep moisture gradient at the beginning of the drying, however, is of much assistance. Such a gradient may be secured by the use of low humidities, but they may have to be accompanied by low temperatures to prevent injury to the stock. In some cases sumply the use of low temperatures at the beginning of the run, without unusually low humidities, seems sufficient.

STRESS DETECTION

The detection and the relief of the shrinkage stresses causing casehardening, checking, and honeycombing are among the most important of the kiln operator's duties; they require special skill and close application. The usual method of detecting the presence of these stresses, which commonly are called casehardening stresses, is to cut a stress section from an average board. Such a section should be cut at least 2 feet from the end of the board, and should be about 1 inch long in the direction of the grain. It must be slotted somewhat as shown in Figure 8, the exact number of slots depending upon the thickness of the board and upon the preference of the individual operator. Often it is desirable to cut off several stress sections, slotting them variously. The direction in which the individual prongs turn and their relative lengths tell the story. If the outer ones turn out, it is an indication of tension in the outer layers. If they turn in, there is compression in the outer layers.

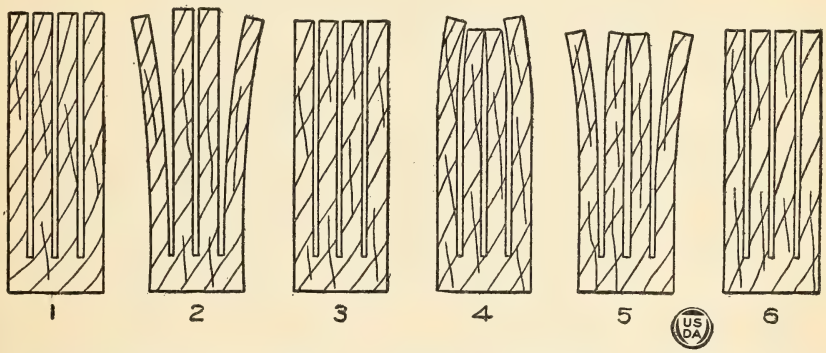


FIGURE 8.—Typical stress sections. 1 represents a green board; 2 indicates tension in the surface, typical of early stages of drying; in 3 drying has progressed enough further than in 2 to make the shrinkage of the interior balance that of the surface; 4 shows typical casehardening; 5 reveals slight reversal of the stresses in 4 by treatment to relieve casehardening; and 6 is the finish board, free from stress. The changes in the length of the prongs have been exaggerated slightly for clearness

Slotting the stress section into prongs frees groups of layers, which had been locked in a common restraint, allowing each group to make a new adjustment within itself. The tension side of each will immediately contract and the compression side will stretch, just as a spring under tension or under compression will change its length when the deforming pressure is removed. In doing this the prong will be bent, the amount of the bend depending upon the thickness of the prong and upon the magnitude of the stress originally present. The side that was originally in tension will become concave and the one originally in compression will become convex. The comparative values and the distribution of the drying stresses can be judged by the relative bending of the several prongs, especially when they all turn outward.

When some prongs of a stress section turn inward, however, the relative bending can not be judged so well, since interference is

then likely to occur. In such cases it may be advantageous to cut the section into a larger number of prongs, thus reducing the degree of curvature in each and hence permitting surer comparison of the relative lengths of the individual ones. If they are thin enough there will be but little difference in stress between the opposite sides of each prong, and its state of stress will consequently be correctly indicated by the change in its length.

All stress-section prongs in tension at the time of cutting will shorten, and those in compression will relieve themselves by lengthening. The outer ends of such prongs will form a curve, as shown roughly by sections 2 and 4 of Figure 8, and the shape of this curve will indicate clearly the state of stress. If it is convex or high in the center, as in section 2, it denotes tension in the outer layers and compression in the core. If low in the center, it means the reverse.

So far only general indications at the time of sawing have been considered. If the sections are now set aside in a suitable place they will soon dry down to an approximately uniform moisture content, the actual value depending upon the temperature and the humidity of the surrounding atmosphere, and these last changes in the moisture content of the section will be made evident by further changes in the length and in the curvature of the individual prongs. Loss of moisture on one side of a thick prong will usually be most plainly shown by a change of shape, the prong bending toward the side that has just been drying. If, however, there is an equal loss of moisture from both its sides, which may happen if it is in the middle of a section, the only indication will be a shrinkage in its length. In sections taken from thin lumber this is apt to be the fact anyway, because the very thinness precludes much difference in moisture content between the two sides of the board and allows still less between the sides of a prong.

Under ordinary circumstances, the final drying of a stress section will cause a contraction or an inward turning, or both, to take place in all the prongs, the amount in each prong being dependent upon the amount of moisture lost from the individual prong. Except when steaming or other conditioning treatment is given the stock in the kiln after the stress section has been taken out, the final shape of the entire section is a criterion by which to judge what the condition of the stock will be after the drying has been completed. Caution must be used in judging, however, since the sections dry without further stress and the stock in the kiln probably does not. The more nearly dry the stock is when the stress section is cut, the more reliable an indicator will it be in this respect.

The following key interprets the significance of the behavior of the stress sections when they are first cut and then after room drying. In using this key and in comparing various sections one with another it must be remembered that the thickness of the stock and the width and the number of the prongs have an important bearing upon the appearance and the behavior of the individual sections.

KEY FOR DETERMINING FROM STRESS SECTIONS THE PROBABLE CONDITIONS IN LUMBER DURING SEASONING

1. *When the prongs turn out on sawing.*—The surface is in tension (attempting to shrink), and the center is in compression (opposing surface shrinkage).
   - A. If the prongs turn in after room drying—
     - Indication of unequal moisture distribution, with the surface drier than the center.
     - Occurrence: In the early stages of drying.
     - Remarks: The lumber does not need steaming at this time. If a tendency to surface check is noticed, use a higher humidity to retard surface drying.
   - B. If the prongs do not change after room drying—
     - Indication of practically equal moisture distribution, with the surface in tension and the center in compression.
     - Occurrence: After oversteaming at a low moisture content.
     - Remarks: The lumber should have received less severe steaming treatment.
2. *When the prongs turn in on sawing.*—The center is in tension (attempting to shrink) and the surface is in compression (opposing center shrinkage).
   - A. If the prongs pinch tighter after room drying—
     - Indication of unequal moisture distribution, with the surface drier than the center.
     - Remarks: An advantageous point to relieve stresses by steaming.
   - B. If the prongs become straight or turn out after room drying—
     - Indication of unequal moisture distribution, with the center drier than the surface.
     - Occurrence: After steaming and before redrying.
     - Remarks: After redrying the prongs should remain practically straight.
3. *When the prongs remain straight on sawing.*—The lumber is free from stresses.
   - A. If the prongs remain straight after room drying—
     - Indication of freedom from stresses, with equal moisture distribution.
   - B. If the prongs turn in after room drying—
     - Indication of unequal moisture distribution, with the surface drier than the center.
     - Remarks: A short steaming treatment to balance the moisture content should relieve all stresses.
   - C. If the prongs turn out after room drying—
     - Indication of unequal moisture distribution, with the center drier than the surface.
     - Occurrence: During some period of redrying after steaming.

STRESS REMEDIES

The prevention of stress troubles in a kiln charge, as far as that is possible, is even more desirable than remedying them. The condition of stock entering the kiln should be carefully determined, so that its subsequent treatment may be suitable.

STEAMING

A high-humidity treatment of a kiln charge, which for convenience is ordinarily called a "steaming," is a treatment at a humidity that corresponds at least to the moisture content of the surface of the lumber. The first steaming should, as a rule, be comparatively mild in order to avoid the possibility both of honeycomb during the treatment and of the opening up of old surface checks or the formation of new ones during subsequent drying, even when it is given only in order to warm the stock before drying commences. In fact, if the stock has

checked during air seasoning, and particularly if it is so dry that the checks have closed up, great care must be exercised to see that the surface is not moistened too much during any high-humidity treatment. If it is, checks that would otherwise be closed when the drying process is over will open up glaringly.

RELIEF OF SURFACE TENSION

Among kiln operators it is common practice to steam air-dried or partially air-dried lumber initially for the purpose of reducing the tension set in the outer layers of the individual pieces. This practice has degraded a large amount of such lumber, not because steaming at the initial stage of the drying process is in itself fundamentally wrong, but because the customary manner of doing it is wrong. Initial steaming is often unessential, and it is far better not to steam air-dried lumber than to give the treatment improperly.

The first evidence of stress in fresh stock in the kiln is a tension in the outer portion of a piece (the shell), which appears in the stress section in an outward turning of the prongs. Such tension may be considered a normal condition, more or less unavoidable. If it becomes too severe, however, surface checks will result. The condition of the stock in the early part of the run is usually judged by the presence or the absence of surface checks. Excessive tension in the surface and resulting surface checks are caused by too steep a moisture gradient; in other words, the moisture content of the surface layers, under this condition, is too low in comparison with that of the core. The remedy is to raise the moisture content at the surface by raising the relative humidity of the air in the kiln, thereby reducing the moisture gradient. (Refer again to fig. 6 to consider the effect of raising to a higher position the ends of any one of the curves.)

Although successful methods of steaming lumber have for the most part been worked out empirically, there is one basic principle that must be grasped before steaming treatments can be given intelligently, namely, before a set expanded condition in the outer layers of a piece can be reduced, this portion of it must be made to fail permanently in compression across the grain, that is, these layers must take a compression set. Such failure necessitates the following conditions: (1) An interior below the fiber-saturation point, (2) an exterior tending to swell across the grain because of the raising of its moisture content above that of the interior, and (3) a resultant increase in stress in the wood sufficient in value and in duration to cause a permanent compression deformation across the grain in the exterior of the piece.

A general rule is that the humidity during the initial steaming of air-dry stock should correspond to a moisture content 2 or 3 per cent higher than that of the surface layers of the stock and that the treatment should continue until the surface quarter inch has absorbed moisture enough to bring it into equilibrium with these humidity conditions. The time required for such a steaming, once the conditions proper for it have been attained, will vary for 1-inch stock from a few hours to a day, depending upon both species and individual conditions. To hasten the treatment and to warm up the stock most satisfactorily, it is customary to use a temperature about 15° F. higher than that at which drying is to commence.

Preliminary steaming of green stock.—The first steaming of stock that is put into the kiln in a totally undried condition is solely to warm it. The procedure is outlined on page 47.

RELIEF OF INTERNAL TENSION

Assume that the stock has safely passed the first stages of drying, and that the stress in the outer portion of each piece has changed from tension to compression. During this period of the process the stock usually is not liable to injury, and the only surface phenomenon is that the checks close up. The surface compression existing will naturally be accompanied by a corresponding tension in the cores. If surface checks were originally present and have closed up, such increasing tension is more likely to produce honeycombing than if the stock had never been surface checked. In any event, the greater the tension stress across the grain in the center of a piece the greater is the danger of the wood failing internally in tension across the grain (honeycombing). Now the degree of tension that ultimately develops in the interior of a piece of wood depends on the degree to which the surface is set in an expanded condition. Honeycombing, therefore, can largely be prevented by carrying high relative humidities during the period in which set is developing in the lumber.

The shell of a piece of air-dried lumber, however, is usually set in an expanded condition when the stock enters the kiln, so that in general it is not the relative humidity used in the kiln schedule that governs the extent to which the core of such a piece is stressed during subsequent kiln drying; the degree of stress during kiln treatment depends chiefly on the drying conditions that existed during the previous air-seasoning process. The relative humidity specified in a drying schedule, therefore, has little to do with the prevention of honeycombing in the usual kiln charge. The temperature carried has a bearing on such prevention, though, because hot wood will honeycomb under smaller stress than cool wood.

With 6/4-inch and thinner partially dried stock, it ordinarily is safe practice so to adjust the relative humidity in the kiln that the moisture content of the surface of the stock will be raised to the value of the core content. This treatment will usually have a desirable effect on the surface, moistening and softening it and temporarily increasing the compression in the outer shell, which in the semiplastic condition thus caused fails permanently under the increased load, taking a compression set across the grain. In this way the set expanded condition is decreased. Almost immediately after the steaming treatment the surface layers will lose most of the moisture picked up, and if the treatment has been properly conducted, with respect to duration, temperature, and relative humidity, the stock will then be stress-free. On the other hand, if the relative humidities employed have been too high the stresses in the surface layers will be reversed. The outer prongs in a casehardening stress section will then turn outward.

Prevention of reverse casehardening.—When stock is reasonably dry and the compression shell of each piece is comparatively thick, a steaming treatment at too high a relative humidity may readily result in too severe an effect on the surfaces without enough effect toward the deeper portions of the shells. If the treatment is con-

tinued long enough to penetrate the shells entirely, the surfaces may pick up so much moisture that the resultant great shrinkage occurring during redrying will produce a permanent reverse casehardening, which the drying down to the desired final moisture content will not eliminate. This state of affairs must be avoided, since reverse casehardening in dry stock can be removed only through softening up the entire piece again—a tremendously long and unsatisfactory process. It is better, therefore, to employ relative humidities no higher than those necessary to eliminate the casehardening.

GENERAL RULES FOR STEAMING

Inflexible rules for steaming treatments to relieve casehardening can not be laid down, largely because it is impossible to express the degree of casehardening itself with numerical exactness; each operator will have to learn by experience just what can and must be done with each individual kiln charge. Steaming at the saturation point (100 per cent relative humidity) may, in general, be done satisfactorily only with green stock (as a preliminary treatment) or with stock in which the moisture in the core is above the fiber-saturation point and the moisture content of the surface is not below 18 per cent. For drier stock lower humidities should be used. The relative humidity of the air should be adjusted to correspond, during the steaming treatment, to the desired final surface moisture content. Suppose, for instance, that the surface moisture content is 10 per cent, and it is desired to raise it to 13 per cent, the temperature of the treatment being 180° F. At this temperature, a relative humidity of about 82 per cent is in balance with a moisture content of 13 per cent (fig. 4) and the treatment, therefore, should be given at that humidity. Comparatively high temperatures are usually carried for final steaming treatments; for hardwoods they customarily range up to 165° F. and for softwoods they may rise as high as 200° F. Steaming at high temperatures will be discussed further in connection with the special softwood drying schedules (p. 56).

Casehardening is not in itself a serious defect during the drying process, but is undesirable because it leads to various other difficulties. In the finished stock, however, matters are different; casehardening then is of itself a serious defect, one that results in warping, unequal shrinkage, and similar trouble, especially in resawing or in working deep patterns. It is almost essential, therefore, that casehardening in such stock be remedied before the stock is taken from the kiln, and accordingly provision for a final conditioning treatment should be made in the drying schedule. While final conditioning is not customary in the drying of most softwoods, it has repeatedly been shown that, especially for resaw stock, final relief of casehardening is highly advantageous even in woods like the pines. There are, on the other hand, many cases, such as drying simply to reduce shipping weight, where the financial advantage is questionable.

RELIEVING CASEHARDENING DURING STORAGE

Sometimes a suitable final steaming treatment can not be given—for instance, in a typical progressive kiln. Under such circumstances it is desirable to relieve casehardening stresses, to the extent pos-

sible with this method, by drying to a relatively low moisture content and then bulk piling the stock for storage in a suitable space, preferably one that can be heated to about 25° F. above the outside temperature. The extent to which these stresses will die out during storage varies greatly among different species. As a rule the softwoods react very favorably, but many of the hardwoods, such as the oaks, for instance, are quite resistant, and severe drying stresses consequently are likely to remain almost indefinitely. On the other hand, it undoubtedly is true that wood exposed during service to widely varying atmospheric conditions will normally tend to relieve itself of casehardening stresses. The relief of such stresses during storage and in use depends upon the pick-up of moisture and the resultant compression set. Without this pick-up and set, relief can not be obtained. (See also " Storage of kiln-dried stock," p. 68.)

KILN DRYING TO KILL FUNGI AND WOOD BORERS

The kiln operator is frequently confronted with the necessity of handling stock showing evidences of decay, mold, or stain, or of the action of borers. Under ordinary drying conditions in the kiln, some borers will be killed, and the growth of decay, molds, and stains of fungous origin will be arrested. When drying is carried on at low temperatures and high humidities, however, the conditions are favorable to the growth of many of these parasites, and they may at times cause trouble in the kiln. The growth of mold on semigreen stock during the early stages of drying is not uncommon.

About 180° F. is required to kill many of the borers, such as the Lyctus powder-post beetle, that infest wood, although considerably lower temperatures will suffice for some. When wood infested by heat-endurant borers has not been subjected to a temperature of 180° F. or higher during the drying process, the kiln temperature should be raised to 180° F. at the end of the run and so held for a half hour or longer, the exact time depending upon the thickness of the stock. If the moisture content of the wood does not exceed 12 per cent and if the relative humidity during the heating period is controlled so as to prevent any visible damage, it is improbable that subjecting the stock to 180° F. for two or three hours will injure the strength of the wood.

The steaming of sap gum before air drying is discussed on page 66.

DRYING SCHEDULES

A drying schedule is a set of brief directions for the operation of the kiln during the drying period. Such schedules are usually presented in the form of curves or of tables showing the temperatures and the humidities to be used at various stages of the process, it being taken for granted that a kiln of suitable type, with ample and uniform circulation, is available; obviously, successful drying can not be accomplished if the kiln is incapable of doing the work required of it. The temperatures and the humidities in drying schedules are based upon either the length of time the stock has been in the kiln or the current moisture content of the stock. The

forest products laboratory prefers the latter basis, using it wherever possible.

The nature and use of the schedules are discussed later, beginning on page 47.

KILN SAMPLES

The successful employment of a drying schedule based upon the current moisture content of the kiln charge requires a system by which this content can be determined with both ease and certainty. The best system so far developed depends upon the use of kiln samples. These samples are short pieces of typical stock of known original moisture content which, placed in representative parts of the kiln, are allowed to dry with the rest of the charge and are periodically weighed to determine the loss in moisture of each of them. Their current moisture-content values are then computed from the original moisture-content values and the losses in weight, and the average of the current values is assumed to be the average moisture content of the entire kiln charge.

Kiln samples are prepared as follows: Several pieces, representing both fast-drying and slow-drying stock, but usually not sapwood, are selected from the stock to be dried, and from each of them one or more samples fully 2 feet long are cut. In order to avoid the uncertainty in the condition of the ends usual with lumber, the samples should, if possible, be cut not less than 2 feet from the end of the piece. A moisture section should immediately be taken from each end of each sample, and the moisture determinations should be carefully made. The average of the results from each pair of sections is assumed to be the average moisture content of the corresponding sample.

END COATINGS

When the moisture sections cut from the kiln samples have been weighed and placed in the oven the samples should be end coated. It has already been shown that wood dries out much faster from end grain than from side grain, and if their end surfaces were not protected in some suitable manner the comparatively short samples would soon become drier than the rest of the stock and would then fail to represent average conditions in the kiln charge.

The end coatings commonly used are of two classes, those liquid at ordinary temperatures, which can be applied cold, and those solid at the same temperatures, which must be applied hot. Either the cold or the hot coatings can be used effectively for drying temperatures up to 140° F. Temperatures much above this cause blistering in the cold coatings, but make the hot type plastic enough to form a new surface as fast as the old one breaks. For this reason the hot coatings are likely to be more effective than the cold for temperatures from 140° up to 170° F., where they liquefy to such an extent that they run off. No coating has been found that is entirely satisfactory for temperatures above 170° F. Cold coatings are perhaps somewhat better than hot for all uses in temperatures above 170° F., and in addition for any kiln samples that may be placed in temperatures below this value but still high enough to cause the loss of part of a hot coating, with the resultant error-making change in the weight of the sample. Some asphalts are strongly moisture-resist-

ant, but they are hard to apply because of the high temperatures required to make them plastic. Paraffin has proved unusually satisfactory as an end coating for stock during air seasoning, but it can not be employed in the kiln because of its low melting point.

Cold coatings should have about the consistency of heavy sirup. The amount of filler required for them ranges from one-half to 4 parts by weight to 1 of the vehicle. They, of course, must be allowed to dry a few hours before being subjected to kiln temperatures. The two best cold coatings developed at the forest products laboratory are hardened gloss oil thickened with barytes and fibrous talc, which is very cheap, and high-grade spar varnish and barytes, a more expensive mixture.

The gloss oil coating is made as follows: The oil itself should be a thick grade, made up (by a paint manufacturer) of about 8 parts of quicklime, 100 parts of rosin, and 57.5 parts of a thinner, such as mineral spirits. To 100 parts of the gloss oil add 25 parts of barytes and 25 parts of fibrous talc. One or two parts of lampblack may also be added if a black coating is desired. The fibrous talc helps to prevent the settling out of the pigment. Any paint manufacturer can make up this coating. It can also be mixed by the user as needed, if the proper grade of gloss oil is obtained.

A list of the most usual hot dips follows. They are effective in the order given.

213° coal-tar pitch (inexpensive).
254° coal-tar pitch (inexpensive).
Rosin and lampblack; 100 parts of rosin to 7 parts of lampblack (moderate in cost).

When hot dips are used, the wood should be dipped one-half inch into the liquid.

Excessive shrinkage of the wood and also rough handling often cause the end coating to chip or to shear off, and a fresh application of coating material must then be made; when this is necessary, the weight of the sample must be corrected accordingly. To reduce end drying sufficiently the coating, either original or patched, must cover the entire end surface and must also be sufficiently thick.

Although coating the ends of kiln samples is imperative, such treatment of all the stock in the kiln is desirable only in difficult drying and is considered economically justified solely in unusual cases, such as the drying of heavy vehicle parts, gunstock blanks, and shoe-last blocks.

WORKING UP OPERATING DATA

The oven-dry weight of the kiln sample is found by multiplying its original weight by 100 and then dividing by 100 plus the moisture content expressed in per cent. Assuming that the sample originally weighed 3.75 pounds and that the first two moisture sections averages 25 per cent moisture, the oven-dry weight of the sample is $\frac{3.75 \text{ pounds} \times 100}{100 + 25} = 3$ pounds. If the moisture content were expressed as a decimal instead of in the form of percentage, this formula would be still simpler; the oven-dry weight then is $\frac{3.75 \text{ pounds}}{1.25} = 3$ pounds.

Although the kiln samples must be placed in the kiln charge at points where they will dry neither faster nor slower than the stock immediately around them, they must also be readily accessible for weighing. Whenever a current weight is taken, the current moisture content is always calculated on the basis of the oven-dry weight previously determined, just as if the sample were a regular moisture section, and the moisture content of the entire kiln charge is assumed to be the average of the moisture-content values of the various samples. This method of estimating the moisture content of a kiln charge is subject to several kinds of errors, and the satisfaction derived from its use will depend largely upon the skill and the judgment of the operator. The end coating, for example, may introduce errors in both directions. If a heavy coating, which in itself does not dry out, is applied, the current calculated moisture content will always be higher than the actual content because of the retention by the coating of weight that it would lose if it were wood. On the other hand, if the coating chips off, the loss in weight is credited to moisture loss, and the current calculated moisture content will be too low; replacing such a coating loss too generously will make this calculated moisture content too high. If the end coating is insufficiently resistant to the passage of moisture, the samples will dry out faster than the full-length boards and will, therefore, indicate a moisture content too low for the kiln charge. Further, it has been found by experience, though no entirely satisfactory explanation has been discovered, that for green stock, particularly with softwoods, the kiln samples consistently show a lower moisture content, when dry, than the rest of the kiln charge. On account of these various facts it is desirable to make moisture determinations on the samples at the end of the run, for comparison both with the calculated values for the samples and with the final moisture determinations on the kiln charge proper.

In addition to the usual minor errors possible when working with kiln samples, however, important variations in moisture along the length of a sample may exist in certain species, cypress, for instance, and in such species the moisture content of a sample may be quite different from the average content of its two moisture sections. Another method may be found practical for stock of this kind, a method by which the dry weight of the sample is determined direct from the dry weight and the size of the moisture sections. The proper use of this method requires the sample to be of uniform cross section, and the moisture sections must be both cut square with it and of uniform length along the grain. The dry weight of the sample is then calculated as the total dry weight of the two moisture sections times the length of the sample, divided by the combined length of both sections; in other words, the dry weights of the uniform pieces are proportional to their lengths. Once the dry weight of the sample has been calculated, the rest of this method is the same as that described in the preceding paragraph.

Stress sections also should be cut from the samples at the end of the run; in fact enough samples should be placed in the kiln so that current stress and moisture determinations may be made as often as desired.

USE OF THE DRYING SCHEDULES PRESENTED HERE

Drying schedules must meet the conditions of actual service, and since these conditions are quite variable it is impossible to set up a single series of exact schedules that will have universal application. The condition of the stock as the result of previous seasoning determines to a large degree the preliminary steaming treatment and the initial stages of the drying proper for it, and the purpose for which the dry stock is to be used largely governs the severity of the schedule and the final treatment for stress relief. In addition, the kind of kiln has an important bearing upon the suitability of a schedule and upon the manner of its application. For instance, if it is desired to dry green hardwoods in a kiln having sluggish circulation, the use of high humidities at the beginning is impractical, and it becomes necessary to start the drying at a somewhat lower temperature, with lower humidity, than would otherwise be needed. Again, in drying softwoods, such as pine, in a natural-circulation progressive kiln, a typical high-humidity schedule will fail to give satisfactory results because it will not induce circulation adequate to carry the heat to the lumber and to remove the evaporated moisture. To secure good drying in such circumstances requires a lower humidity at the green end and a higher temperature at the dry end of the kiln. Under ordinary commercial conditions the humidity at the dry end can be comparatively low since the lumber will not be exposed to it long enough to be damaged.

In most progressive kilns and in many softwood compartment kilns operating at high temperatures the use of kiln samples is more or less impractical, and it become necessary to operate the kilns on a time basis. When stock of the same general character is being dried right along, it is possible to secure very satisfactory results in this way.

CHARACTER OF THE SCHEDULES

Most of the drying schedules presented on the following pages are intended for use with kiln samples, the indicated changes in temperature and in humidity being made as the moisture content of the samples passes the various stages. All of these schedules are safe. It is possible to obtain good results with faster drying, but the use of schedules more severe than those recommended will require most careful judgment on the part of the kiln operator.

The schedules of widest application are the hardwood, which were originally intended for furniture stock, and the softwood, which provide for drying at temperatures higher than those of the hardwood schedules. These two series, which supplement each other, are numbered consecutively; No. 000 of the softwood schedules is the most severe, and No. 8 of the hardwood schedules is the mildest.

Preliminary steaming is recommended for green stock, not to relieve stresses but to warm the stock thoroughly before the drying operation begins. It is not necessary to steam green stock so long as partly seasoned stock, one hour per inch of thickness being sufficient. The temperature during steaming may be from 10° to 15° F. above

the starting point of the schedule, and the humidity should be as near 100 per cent (the saturation point) as possible.

In general, the schedules are applicable to the further drying of stock of any degree of seasoning. Once the preliminary steaming, if any, has been given, the drying may be started at the temperature and the humidity corresponding to the moisture content of the stock as it entered the kiln. The whole of the schedule selected will, as a rule, be used only when drying green stock. To illustrate: Suppose a charge of stock at 25 per cent moisture content is to be dried under Schedule 1. The drying conditions proper to start with then are those opposite the 25 per cent on the schedule, namely, a temperature of 155° F. and a humidity of 60 per cent. As soon as the stock has dried 5 per cent, the kiln temperature is to be raised to 160° F. and the humidity is to be dropped to 50 per cent, and so on until the stock is dry.

Stock that has been air dried usually has a more moderate moisture gradient than stock that has reached the same average moisture content in kiln drying and for this reason, if the stock is in good condition, a schedule somewhat more severe than the one specified can be used for it. To do this successfully, however, requires both skill and care.

Each schedule is based on dry-bulb temperatures and relative humidities. The wet-bulb temperatures are the nearest whole numbers, taken from Table 1, that correspond to the kiln temperatures and humidities desired.

The names of woods appearing in the following tables are the standard common names given in the Check List of the Forest Trees of the United States, Miscellaneous Circular 92 of the United States Department of Agriculture.

GENERAL HARDWOOD SCHEDULES

The hardwood schedules in Table 2 are intended for use on lumber of all thicknesses up to about six quarter inches. Thicker stock can be dried by using a schedule one number higher (milder) for each additional inch in thickness. The schedules have been made up for the drying of only one species and one thickness at a time, and for heartwood. In drying hardwood it is unnecessary, as a rule, to segregate the stock by grade or by character of sawing (quartered or plain), and in most cases no attention need be paid to sapwood, except to be sure that none is present in the kiln samples. Sapwood is much easier to dry than heartwood in practically all hardwoods and will dry much faster with a given schedule. In some species, such as red gum, it is sometimes possible to segregate the sap boards and to dry them separately. When this can be done a relatively large saving in time can be effected, especially with green stock (p. 60).

TABLE 2.—*General hardwood kiln-drying schedules 1 to 8*

(D=dry-bulb temperature; W=wet-bulb temperature; H=relative humidity)

Moisture content at which changes should be made, per cent	Schedule 1			Schedule 2			Schedule 3			Schedule 4		
	D	W	H	D	W	H	D	W	H	D	W	H
	° F.	° F.	Per cent	° F.	° F.	Per cent	° F.	° F.	Per cent	° F.	° F.	Per cent
45 or more	140	132	80	135	128	80	130	123	80	125	118	80
40	145	135	75	140	130	75	135	126	75	130	121	75
30	150	137	70	145	133	70	140	128	70	135	123	70
25	155	136	60	150	132	60	145	128	60	140	123	60
20	160	135	50	155	131	50	150	127	50	145	122	50
15	165	127	35	160	124	35	155	124	40	150	120	40
10 to final	170	116	20	165	112	20	160	115	25	155	111	25

Moisture content at which changes should be made, per cent	Schedule 5			Schedule 6			Schedule 7			Schedule 8		
	D	W	H	D	W	H	D	W	H	D	W	H
	° F.	° F.	Per cent	° F.	° F.	Per cent	° F.	° F.	Per cent	° F.	° F.	Per cent
45 or more	120	113	80	115	108	80	110	105	85	105	101	85
40	125	116	75	120	111	75	115	108	80	110	104	80
30	130	119	70	125	114	70	120	111	75	115	107	75
25	135	121	65	130	116	65	125	112	65	120	109	70
20	140	120	55	135	116	55	130	112	55	125	110	60
15	145	119	45	140	115	45	135	110	45	130	109	50
10 to final	150	112	30	145	108	30	140	108	35	135	107	40

Study of these schedules draws attention to the fact that, for a given equilibrium moisture content, in the mild schedules the temperatures are lower and the humidities are higher than in the severe schedules. The moisture gradients, as a result, will be less steep with the milder schedules. Further, high final humidities preclude the possibility of drying to a low final moisture content. For example, the final conditions in Schedule 8, namely, 135° F. and 40 per cent humidity, correspond to an equilibrium moisture content of about 6 per cent, and it would be impossible, under these conditions, to secure a final moisture content lower than this no matter how long the drying was continued. Moreover, getting a moisture content less than 8 per cent would take too long. When low final moisture-content values are desired with the mild schedules, therefore, it will be necessary to use final humidities lower than those shown. A good rule to follow in doing this is to keep the kiln conditions 3 per cent below the current moisture content of the stock. The departure from the schedule will, in no event, need to be made until after the stock has passed 9 per cent moisture content, since the final humidity in Schedule 8, the mildest one, already corresponds to an equilibrium moisture content of 6 per cent, which is 3 per cent lower than the 9 per cent.

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TABLE 3.—*Index of general kiln-drying schedules for various hardwood species, to use with lumber up to six quarter inches in thickness*

Species of wood	Hardwood schedule	Remarks	Species of wood	Hardwood schedule	Remarks
Ash	2		Mahogany	4	
Basswood	1		Maple, silver and sugar.	3	
Beech	3		Oak, red and white	6	Northern highland stock.
Birch	1		Do	7	Northern lowland stock.
Boxwood	5	Squares or quartered stock only.	Do	7	Southern highland stock.
Butternut	2		Do	8	Southern lowland stock.
Cherry, black	5		Osage orange	5	
Chestnut	2		Persimmon	5	
Cottonwood	2		Poplar, yellow	1	
Elm	2		Sycamore	5	
Gum, red	2	See special schedule for sap gum.	Teak (girdled)	2	Burmese: For Java, nese teak use next milder schedule.
Gum, black and tupelo.	3		Teak (ungirdled)	3	
Hackberry	2		Walnut, black	5	
Hickory	5		Willow	2	
Holly	4				
Hop hornbeam (ironwood).	4				
Locust	5				
Magnolia	4				

Red gum.—The hardwoods, as a rule, are more plastic when hot and moist than the conifers are, and, in consequence, are more easily bent. A modification of this fact is taken advantage of in the drying of red gum, which at high temperatures seems plastic enough to overcome its natural tendency to warp, and dries with no great trouble if properly stickered (p. 79).

GENERAL SOFTWOOD SCHEDULES

Although the basic principles in the construction and the use of both hardwood and softwood schedules are identical, a slight difference in the arrangement of the two kinds seems necessary. Because of large variations in the initial or " green " moisture content existing among the several softwoods, each of the general softwood schedules is presented in Table 4 in several divisions; the divisions of the same schedule differ from one another only in the values of moisture content at which the changes in temperature and in humidity are to be made.

Further, because of quite wide differences in the drying requirements of various grades and sizes of lumber even in a single species of softwood, it has been found desirable, in several instances, to make drying recomemndations for individual grades or for special sizes, and a number of special schedules have been developed to cover unusual needs. In addition, the type of kiln has an important bearing on the matter. The initial entering-air humidity of 70 per cent, given in the softwood schedules, can be maintained only under favorable conditions. With fast-drying woods the humidity of the air increases rapidly in its passage through the lumber, and, unless the circulation is brisk, air entering the lumber at 70 per cent humidity may become almost or quite saturated before it leaves the pile. This

causes uneven drying even in the same pile, and the situation, of course, is worse over the entire kiln than in any one part of it. Besides, at high humidities even slight differences in temperature in various parts of the kiln cause comparatively wide variations in the drying rate. It is impractical, therefore, to use high initial entering-air humidities in kilns that do not have fast circulation and uniform temperature throughout. Lower initial entering-air humidities must be employed in kilns with slow circulation and also in those lacking uniformity in temperature. The slow circulation compensates in large measure for the lower entering-air humidity, since the humidity rises rapidly as the air passes through the pile; in consequence only a small portion of the lumber is subjected to its lowest value.

In drying thin stock it is possible in the case of a number of species, particularly southern pine and Douglas fir, to secure first-class results with initial entering-air humidities below 70 per cent in kilns having rapid circulation. On the other hand, particularly in wide stock, some checking may occur even with initial entering-air humidities as high as 70 per cent. Accordingly the operator will need to experiment more or less to determine the particularly initial entering-air humidity that will give the best results with the particular stock to be dried and with the equipment available.

Preliminary steaming of softwoods is the exception rather than the rule, but it has been found desirable in several special instances.

The final humidities in these schedules will be satisfactory for many progressive kilns, yet in forced-circulation compartment kilns they may at times prove to be too low.

The final temperatures may be found to be too low, for progressive kilns, to give circulation enough to carry off the evaporated moisture.

The softwood schedules are used as follows: Find in the species table (Table 5) the kind and the size of stock to be dried and note the schedule and the division given opposite it. Use the division thus specified, without reference to any of the other divisions in the schedule. Suppose 4/4-inch Douglas fir is to be dried. The table shows two schedules, 000–IV and 00–IV, for 4/4 to 6/4 inch Douglas fir. The more severe one is for the ordinary run of stock and the milder one for wide, flat-grain stock. There is also a general note following Table 4 stating that in drying vertical-grain flooring strips the temperatures may be raised 10° F. higher than those of the schedules, after the stock has dried down to 25 per cent moisture content. Therefore, if the 4/4-inch Douglas fir is flooring strips of this type, use Schedule 000–IV of Table 4, raising the temperature to 200° F. at 25 per cent and to 210° F. at 13 per cent. If it is ordinary stock, use Schedule 000–IV without change, and if it is wide, flat-grain stock, use 00–IV.

These softwood schedules are not intended for low grades of stock. Several special schedules for the lower grades of Douglas fir and southern pine are presented on succeeding pages.

TABLE 4.—*General softwood kiln-drying Schedules 0, 00, and 000*

SCHEDULE 0

Moisture content at which changes should be made, per cent			Dry-bulb temperature	Wet-bulb temperature	Relative humidity
Division I	Division II	Division III			
			° *F.*	° *F.*	*Per cent*
35 or more	30 or more	25 or more	135	123	70
30	25	20	150	126	50
20	16	13	165	132	40
15	12	10	175	130	30

SCHEDULE 00

Moisture content at which changes should be made, per cent				Dry-bulb temperature	Wet-bulb temperature	Relative humidity
Division I	Division II	Division III	Division IV			
				° *F.*	° *F.*	*Per cent*
45 or more	40 or more	35 or more	30 or more	160	146	70
40	35	30	25	170	144	50
20	16	13	13	180	135	30

SCHEDULE 000

Moisture content at which changes should be made, per cent				Dry-bulb temperature	Wet-bulb temperature	Relative humidity
Division I	Division II	Division III	Division IV			
				° *F.*	° *F.*	*Per cent*
45 or more	40 or more	35 or more	30 or more	180	165	70
40	35	30	25	190	161	50
20	16	13	13	200	150	30

Temperatures for vertical-grain flooring strips may be 10° F. higher than those in the schedules, after the stock has dried to a moisture content of 25 per cent.

TABLE 5.—*Index of general kiln-drying schedules for various softwood species, to use with different thicknesses of lumber*

Species of wood	Size of lumber in inches	Softwood schedule	Remarks
Cedar, Port Orford	4/4–6/4	00–III	
	7/4–9/4	00–IV	
Cedar, western red	4/4–6/4	00–IV	Wide, clear (after sinker stock has been removed).
	4/4–6/4	0–III	Sinker stock.
	7/4–9/4	00–III	Free from sinker stock.
	7/4–9/4	0–III	Sinker stock.
	10/4–12/4	0–III	
Cedar, northern white and southern white.	4/4–6/4	00–II	Flat grain.
	7/4–9/4	00–III	
	10/4–12/4	0–II	
Cypress, southern	4/4–6/4	00–I	
	7/4–9/4	00–II	
	10/4–12/4	0–I	
Douglas fir	3½–4½	00–IV	Cross arms.
	4/4–6/4	000–IV	
	4/4–6/4	00–IV	Wide, flat grain.
	7/4–9/4	00–IV	
	10/4–12/4	0–III	

TABLE 5.—*Index of general kiln-drying schedules for various softwood species, to use with different thicknesses of lumber*—Continued

Species of wood	Size of lumber in inches	Softwood schedule	Remarks
Fir, balsam	4/4–6/4	000–I	Wide, flat grain.
	7/4–9/4	000–II	Do.
	10/4–12/4	0–I	
Fir, lowland white	4/4–6/4	000–I	
	4/4–6/4	00–I	Do.
	7/4–9/4	000–II	
	7/4–9/4	00–II	Do.
	10/4–12/4	0–I	
Fir, noble	4/4–6/4	000–III	
	4/4–6/4	00–III	Do.
	7/4–9/4	000–IV	
	7/4–9/4	00–IV	Do.
	10/4–12/4	0–III	
Fir, white	4/4–6/4	000–I	
	4/4–6/4	00–I	Do.
	7/4–9/4	000–II	
	7/4–9/4	00–II	Do.
	10/4–12/4	0–I	
Hemlock, eastern	4/4–6/4	00–I	
	7/4–9/4	00–II	Do.
	10/4–12/4	0–I	
Hemlock, western	4/4–6/4	000–I	
	7/4–9/4	000–II	
	10/4–12/4	0–I	
Larch, western	4/4–6/4	00–II	Do.
	7/4–9/4	00–III	Do.
	10/4–12/4	0–II	
Pine, Norway	4/4–6/4	000–II	
	7/4–9/4	000–III	
	10/4–12/4	0–II	
Pine, longleaf, shortleaf, and loblolly	4/4–6/4	000–I	
	7/4–9/4	00–I	
	10/4–12/4	0–I	
Pine, western yellow and sugar	4/4–6/4	000–I	Except stock subject to brown stain.
	7/4–9/4	00–I	
	10/4–12/4	0–I	
Pine, northern white and western white	4/4–6/4	00–II	Wide, flat grain.
	7/4–9/4	00–III	Do.
	10/4–12/4	0–II	
Redwood	4/4–6/4	00–I	Free from sinker stock.
	4/4–6/4	0–I	Sinker stock.
	7/4–9/4	00–II	Free from sinker stock.
	7/4–9/4	0–II	Sinker stock.
	10/4–12/4	0–I	
Spruce, Engelmann	4/4–6/4	00–II	
	7/4–9/4	00–III	
	10/4–12/4	0–I	
Spruce, red	4/4–6/4	00–III	
	7/4–9/4	00–IV	
	10/4–12/4	0–III	
Spruce, Sitka	4/4–6/4	000–II	
	4/4–6/4	00–II	Wide, flat grain.
	7/4–9/4	000–III	
	7/4–9/4	00–III	Do.
	10/4–12/4	0–II	
Spruce, white	4/4–6/4	000–III	
	4/4–6/4	00–III	Do.
	7/4–9/4	000–IV	
	7/4–9/4	00–IV	Do.
	10/4–12/4	0–III	
Tamarack	4/4–6/4	00–II	
	7/4–9/4	00–III	
	10/4–12/4	0–II	

SPECIAL SCHEDULES

The hardwood and the softwood schedules together cover almost the entire temperature range commonly used in kiln drying. The values extend from an initial temperature of 105° F. in hardwood Schedule 8 of Table 2 to a final temperature of 210° F. for vertical-grain flooring strips in softwood Schedule 000 of Table 4. While most drying can be reasonably well done by the use of the

proper one of these 11 schedules, it has been found advantageous to develop special schedules for certain purposes. A number of these follow.

AIRCRAFT LUMBER

Many kiln runs and many thousands of strength tests have proved that the aircraft schedules of Tables 6 and 7, if carefully followed, will deliver stock that is just as strong in every way as the most carefully air-seasoned equivalent stock. These schedules, prepared by the forest products laboratory, have been the standard for the Army and the Navy air services since 1917. They are intended for thicknesses of 3 inches or less; with heavier stock the temperature should be lowered 5° F. for each inch increase in thickness.

TABLE 6.—*Special kiln-drying Schedule 101 for aircraft lumber*[1]

Moisture content at which changes should be made, per cent	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	° F.	° F.	*Per cent*
30 or more	120	113	80
25	125	114	70
20	128	112	60
15	138	112	44
12	142	112	39
8	145	110	33
Final	145	110	33

[1] For use with the following species of wood: Ash, blue, white, and Biltmore white; birch, yellow; cedar incense, northern white, western red, and Port Orford; cypress, southern; maple, silver and sugar; pine sugar, northern white, and western white; spruce, red, white, and Sitka.

TABLE 7.—*Special kiln-drying Schedule 102 for aircraft lumber*[1]

Moisture content at which changes should be made, per cent	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	° F.	° F.	*Per cent*
30 or more	105	100	84
25	110	101	73
20	117	103	62
15	129	106	46
12	135	109	43
8	135	107	40
Final	135	107	40

[1] For use with the following species of wood: Cherry, black; Douglas fir; mahogany; oak, red and white; walnut, black.

DOUGLAS FIR

The kiln drying of common grades of softwood lumber often presents problems different from those encountered in the drying of upper grades. One of these problems is to secure a reasonably uniform final moisture content; this problem is of importance when the average final moisture content is comparatively high, say between 15 and 20 per cent, which is present practice in drying common grades of Douglas fir. Another problem is to keep the degrade from loose and fallen knots to a minimum. The best present solution to these problems lies in the use of comparatively low temperatures and of high humidities throughout the kiln run, and to maintain these conditions satisfactorily requires a very rapid and uniform

circulation and an accurate control of both temperature and humidity.

The two schedules following, Tables 8 and 9, have given good results. The drying time under them will vary considerably with the size and the shape of the stock. For 1-by-8-inch material it should be about 32 hours, to secure a final average moisture content of 15 per cent.

TABLE 8.—*Special kiln-drying Schedule 103 for Douglas fir*[1]

Time in the kiln at which conditions shall be established	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	° *F.*	° *F.*	*Per cent*
Beginning of run (initial conditions)	175	160	70

[1] For general use with the following sizes: 1 by 6, 1 by 8, 2 by 4, and 2 by 6 inches.

TABLE 9.—*Special kiln-drying Schedule 104 for Douglas fir*[1]

Time in the kiln at which conditions shall be established	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	° *F.*	° *F.*	*Per cent*
Beginning of run (initial conditions)	175	166	80
End of first half of run	175	160	70

[1] For general use with the following sizes: 1 by 10, 1 by 12, 2 by 8, 2 by 10, and 2 by 12 inches.

The falling out of knots causes more degrade in 1-inch common lumber (especially No. 1 Common) than in other thicknesses of Douglas fir, and one of the mills kiln-drying large quantities of this stock has developed a special schedule for it. Under the schedule the drying temperature is kept constant at 125° F. and the humidity at 70 per cent; the kilns furthermore are operated on a flat time basis, each charge being dried 48 hours. In kilns with reversible circulation a single reversal at the 40-hour point is sufficient. The degrade experienced with this schedule is very small indeed.

This same mill uses a more severe schedule for 2-inch common lumber, with which the drying is completed in the same time, 48 hours. The drying temperature is kept constant at 175° F.; the humidity for the first day is 62 per cent and for the second day 53 per cent. With reversible circulation kilns a single reversal at the 40-hour point is sufficient.

Kiln drying wide, flat-grain finish lumber without surface checking is rather difficult. On account of the value of this stock, however, drying it with extreme care pays well. The schedule recommended for this service, Division IV of No. 00, is a good one for average conditions, but where the very minimum of degrade is desired the special schedule of Table 10, also developed by the same mill, may be used.

TABLE 10.—*Special kiln-drying Schedule 105 for wide, flat-grain Douglas fir finish lumber*

Time in the kiln after which changes should be made, hours	Dry-bulb temperature	Wet-bulb temperature	Relative humidity	Additional instructions
	° F.	° F.	*Per cent*	
0				Start steaming.
3				Reach 150° F. and 100 per cent humidity.
9				Stop steaming.
12	150	147	92	
30	155	147	81	
42	160	147	71	
60	160	140	58	
78	165	140	51	
96	170	140	45	
108	170	130	33	
134	170	130	33	Reverse direction of circulation.
150				Steam at 170° F. and 100 per cent humidity.
152				End of run.

Table 10 is a very slow schedule, with extremely high humidity at the beginning. An unusually rapid and uniform circulation is required to make the use of such a schedule satisfactory.

SOUTHERN YELLOW PINE

In the various species of southern yellow pine, as well as in Douglas fir, the application of special schedules to special items has proved economically sound. Even in particularly troublesome cases the savings from lessened degrade are much greater than the added cost of the more careful kiln drying. The following special schedules, for operation on a flat-time basis, are intended for use with fast-circulation compartment kilns; they apply specifically to longleaf, shortleaf, and loblolly pine, although in general they are satisfactory for all commercial species of the southern yellow pines.

TABLE 11.—*Special kiln-drying Schedule 106 for southern yellow pine*[1]

Time in the kiln after which changes should be made, hours	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	° F.	° F.	*Per cent*
0	175	170	89
5	190	170	63
35	200	160	39
67	190	182	84
72		End of run	

[1] For use with 1 by 3 and 1 by 4 inch No. 2 Common and Better flooring and partition stock.

TABLE 12.—*Special kiln-drying Schedule 107 for southern yellow pine*[1]

Time in the kiln after which changes should be made, hours	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	° F.	° F.	*Per cent*
0	180	175	89
5	190	170	63
35	200	170	51
59	210	170	41
91	190	182	84
96		End of run	

[1] For use with 1 by 6 inch and wider No. 1 Common and Better lumber.

TABLE 13.—*Special kiln-drying Schedule 108 for southern yellow pine*[1]

Time in the kiln after which changes should be made, hours	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	° F.	° F.	*Per cent*
0	175	170	89
5	190	170	63
35	200	170	51
67	190	182	84
72	End of run.		

[1] For use with 1 by 6 inch and wider No. 2 Common lumber.

TABLE 14.—*Special kiln-drying Schedule 109 for southern yellow pine*[1]

Time in the kiln after which changes should be made, hours	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	° F.	° F.	*Per cent*
0	175	170	89
5	180	170	79
10	190	170	63
35	200	170	51
85	200	160	39
115	190	182	84
120	End of run.		

[1] For use with all widths of 5/4 and 6/4 inch finish stock.

TABLE 15.—*Special kiln-drying Schedule 110 for southern yellow pine*[1]

Time in the kiln after which changes should be made, hours	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	° F.	° F.	*Per cent*
0	175	170	89
5	180	170	79
10	190	170	63
50	200	170	51
108	200	160	39
138	190	182	84
144	End of run.		

[1] For use with all widths of 8/4 inch finish stock.

The conditions of the final steaming periods of five to six hours specified in special Schedules 106 to 110, inclusive, (Tables 11 to 15, inclusive) are unusual in that the kiln temperature in each case is less than the maximum drying temperature of the schedule. The reason for this is the saving effected in total drying expense; correct calculation of the total expense requires taking into consideration both the cost of steam consumed and the cost of time. Although at first glance the facts in the case seem to conflict, the explanation is simple. In the average kiln it is very difficult to maintain a wet-bulb temperature much above 180° F. without a tremendous steam consumption. On the other hand, it is equally difficult to cool the charge quickly from 200° or 210° F. to much less than 190° F., because of the large amount of heat in the stock and in the kiln walls. To obtain the comparatively small difference between dry-bulb and wet-bulb temperatures desired for such conditioning, therefore, in these special schedules each temperature is shifted a little way toward the other,

thus avoiding the severe troubles of an extreme change in either. The compromise reached in this manner has proved thoroughly satisfactory. The operator, however, must be very careful to determine the conditions actually existing in the kiln after the shift; he can not afford to rely simply upon setting the dry-bulb thermostat back to the desired temperature.

In progressive kilns having sluggish circulation it will be necessary to modify the general softwood schedules somewhat; special Schedules 106 to 110, inclusive, of course are not suitable for progressive kilns. One-inch B and Better southern yellow pine lumber can be dried satisfactorily in a kiln of this type under the extreme conditions of a temperature of 180° F. and 70 per cent humidity at the green end and 210° F. and 30 per cent humidity at the dry end.

WESTERN YELLOW PINE

Under certain conditions, not yet fully understood, western yellow pine is subject to a brown stain, sometimes called "kiln burn," which appears at or immediately beneath the surface of the sapwood during kiln drying. No entirely satisfactory method of preventing this stain has been discovered, but a number of operators report that the use of low-temperature schedules, with low humidities, will prevent a large part of it. The following schedule (Table 16), designed for 6/4-inch stock, is typical of such schedules.

TABLE 16.—*Special kiln-drying Schedule 111 for western yellow pine*

Moisture content at which changes should be made, per cent	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	° F.	° F.	*Per cent*
85 or more	120	103	55
80	130	108	48
50	140	112	41
30	150	114	33
20	160	114	24

The schedule given in Table 16 requires about six days' drying time. A final steaming may be given to relieve drying stresses; it can well be at 160° F. and 80 per cent relative humidity, lasting for five hours.

Other operators report successful prevention of brown stain by maintaining high humidities throughout the run and then stopping the drying when the lumber has reached a moisture content of about 18 per cent.

EASTERN RED CEDAR

Eastern red cedar, the southern juniper used for pencils and for cedar chests, is dried with difficulty; care must be taken to prevent the shelling off of the streaks of sapwood that will result from too steep a moisture gradient and from too severe casehardening. A special schedule (Table 17) has been prepared for the drying of 1-inch boards of this species.

TABLE 17.—*Special kiln-drying Schedule 112 for 1-inch eastern red cedar*

Moisture content of heartwood samples at which changes should be made, per cent	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	° F.	° F.	*Per cent*
25 or more	140	128	70
20	150	127	50
15	155	124	40
10 to final	160	115	25

The cedar oil present in this wood causes a variable error in making moisture determinations, since it is driven out of the moisture sections in the drying oven along with the real moisture, thus giving a calculated moisture content higher than the actual. This error is usually not more than 2 or 3 per cent, though it may be as great as 5 per cent.

OAK WHEEL BLANKS

Several schedules have been developed for oak artillery-wheel stock—club-turned spokes and bent rims. Since oak is extremely variable in its drying characteristics, great care must be exercised in using these schedules. Further, steaming of bent rims must be done with caution, since oversteaming will relieve the set caused by the bending, thus allowing the stock to straighten out. Ordinarily steaming for from one to two hours at 160° to 180° F. may be done periodically after the outer half inch has dried below 25 per cent moisture content.

TABLE 18.—*Special kiln-drying Schedule 113 for 56-inch artillery-wheel spoke blanks, oak, 2¾ by 2¾ by 26 inches*

Moisture content at which changes should be made, per cent	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	° F.	° F.	*Per cent*
80 or more	105	100.5	85
60	106	100.5	82
40	107	100.5	79
30	110	101.5	74
25	115	102	63
20	120	102	53
15	131.5	104	40
10	142	106	30

TABLE 19.—*Special kiln-drying Schedule 114 for 60-inch artillery-wheel spoke blanks, oak, 3¾ by 3¾ by 26 inches*

Moisture content at which changes should be made, per cent	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	° F.	° F.	*Per cent*
80 or more	100	96	86
60	101	96	83
40	102	96	80
30	105	97	75
25	110	98	65
20	115	99	56
15	127	101	40
10	140	103	29

TABLE 20.—*Special kiln-drying Schedule 115 for 56-inch artillery-wheel rims, bent oak, 3½ by 3½ by 56 inches*

Moisture content at which changes should be made, per cent	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	° F.	° F.	Per cent
70 or more	90	83	75
65	95	88	75
60	100	93	75
55	105	97	75
50	110	102	75
35	115	105	70
30	120	105	60
20	130	106	45
15	140	108	35
10	150	107	25

TABLE 21.—*Special kiln-drying Schedule 116 for 60-inch artillery-wheel rims, bent oak, 3¾ by 3¾ by 60 inches*

Moisture content at which changes should be made, per cent	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	° F.	° F.	Per cent
70 or more	85	79	75
65	90	83	75
60	95	88	75
55	100	93	75
50	105	97	75
35	110	100	70
30	115	100	60
20	125	102	45
15	135	104	35
10	145	104	25

SAP GUM

When the amount of red gum (heartwood) or of quarter-sawed sap gum in any kiln charge of gum is so small that it need not be considered, the special schedule of Table 22 is recommended. Green stock for which this schedule is used should be steamed for four hours at 180° F. and at saturation before drying is started.

The steaming of sap gum before air drying is discussed on page 66.

TABLE 22.—*Special kiln-drying Schedule 117 for plain-sawed sap gum up to six quarter inches in thickness*

Moisture content at which changes should be made, per cent	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	°F.	°F.	Per cent
45 or more	165	148	65
40	165	148	65
30	170	150	60
25	175	154	60
20	175	151	55
15	175	135	35
10 to final	175	125	25

WALNUT GUNSTOCKS

Walnut for gunstocks is usually cut in the form of rough blanks, is steamed to darken the sapwood, and is then shipped to the gunmaker for drying. All gunstocks to be kiln dried should be end-coated before they are loaded into the kiln, preferably with 213° coal-tar pitch or filled hardened gloss oil. A schedule that has been used successfully in the drying of many thousand blanks is given in Table 23.

TABLE 23.—*Special kiln-drying Schedule 118 for black walnut gunstock blanks*

Moisture content at which changes should be made, per cent	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
	° F.	° F.	*Per cent*
40 or more	110	102	75
35	113	102	68
20	115	103	66
15	117	103	62
10	130	105	43
8 to final	140	107	34

Steaming walnut to darken the sapwood is usually done in steam boxes, which are chambers adapted to the use of steam at atmospheric pressure. It is customary to steam 1-inch stock about four to five days at a temperature of 140° to 160° F. Either live steam or exhaust steam may be used.

Steam boxes and patent steaming cylinders are discussed incidentally on page 66.

MAPLE SHOE-LAST BLOCKS

Maple shoe-last blocks, end dipped and piled on stickers, can be dried successfully under hardwood Schedule 7 of Table 2.

BENT STOCK

Bent stock of various kinds may be dried according to the lumber schedules applying to the species of wood and the thickness of piece, but, as with oak wheel rims, steaming must be done with caution, since the excessive use of steam in the early stages of such drying is very likely to result in the loss of the bends in the stock.

PLYWOOD PANELS

The drying of plywood panels after they have been glued is a special problem in which simplicity of control and of operation are important. Although such panels can be dried successfully under widely varying conditions of temperature and of humidity, the effect of the drying schedule upon the strength of joint may well be considered. It has been found possible to dry panel stock satisfactorily at a constant temperature and a constant humidity corresponding to a moisture content about 2 per cent below that which the panels are to reach. Thus, if the panels are to come down to 10 per cent, a humidity corresponding to about 8 per cent moisture

content would be used. (Fig. 4.) At a temperature of 120° F., the humidity corresponding to 8 per cent moisture content is about 50 per cent. A temperature of 120° F. and a humidity of 50 per cent will dry the average half-inch panel down to 10 per cent moisture content over night, and no particular damage will result if the stock is left in the kiln appreciably longer, since the drying rate below the desired 10 per cent will be increasingly slow.

Table 24 shows several combinations of temperatures and relative humidities with which a moisture content of 6 to 12 per cent may be obtained in freshly glued plywood within a reasonable drying period.

TABLE 24.—*Combinations of temperatures and relative humidities suitable for drying freshly glued plywood panels to various desired moisture content values*

Moisture content desired, per cent	Relative humidities for use with the temperatures indicated			
	100° F.	110° F.	120° F.	140° F.
	Per cent	*Per cent*	*Per cent*	*Per cent*
6	21	22	24	26
7	28	29	31	34
8	33	35	37	41
10	46	48	50	53
12	58	59	61	65

MISCELLANEOUS FEATURES OF DRYING

OSCILLATING SCHEDULES

In the usual drying schedule, the temperature and the humidity are kept practically constant over comparatively long periods of time and changes in them, when made, are relatively small. In another type of drying schedule, commonly known as an oscillating schedule, the temperature or the humidity or both are made to fluctuate regularly between fixed limits, that is, to oscillate, over quite a wide range at comparatively short intervals, the control being automatic and based either upon fixed time intervals or upon the temperature and the humidity within the kiln. Experiments with various oscillating schedules in small fast-circulation kilns have in general failed to demonstrate any marked superiority of these schedules over the ordinary steady schedules. The makers of oscillating control apparatus, however, claim that these schedules do reduce the drying time and do reduce the amount of drying stress in the lumber. Most of the oscillating controllers now in use are on natural-circulation kilns, and possibly the increased amount of circulation within the kiln that results from the use of large quantities of steam in the steam jets during the periods of increasing humidity tends to produce faster and better drying than that obtained with the original circulation.

DRYING BY SUPERHEATED STEAM

All of the schedules so far presented are adapted to "air" kilns only. Kilns of other types are possible. Superheated steam is capable of absorbing moisture, the amount that it can take up being dependent upon the degree of superheat, and it is therefore a drying

agent. Several years ago two types of superheated-steam kiln were developed and were marketed to quite an extent in the Pacific Northwest, principally for drying Douglas fir and western hemlock; a number of them are still in operation. In these kilns live steam, superheated by means of coils carrying high-pressure steam, is turned into the kiln. The degree of superheat, that is, the increase in temperature above the boiling point of water at atmospheric pressure, governs the drying rate, and no further humidity control is needed. The drying temperatures in such kilns usually range between 225° and 240° F., the exact value in any case depending upon the class of wood being dried and upon the boiling point of water at the atmospheric pressure within the kiln. Sometimes an unusual amount of air is mixed with the steam in the kiln, with the result that the drying capacity of the kiln atmosphere is correspondingly increased. Such a condition is indicated by a wet-bulb reading below the boiling point; the remedy is to carry a lower degree of superheat.

DRYING PERIODS

The extreme variability of the drying time with individual lots of stock and with different types of equipment, added to the variability of the time consumed in steaming and in other conditioning treatments, makes a tabulation of total drying time for usual schedules of doubtful value. About the fastest drying time for lumber of which the forest products laboratory has record is the drying of 1 by 4 inch Douglas fir flooring strips in 24 hours; the slowest is the drying of some southern oak wagon bolsters, which were in the kiln almost a year and then had a 15 per cent moisture content.

The average periods required to dry several common hardwoods are presented in Table 25. While these drying rates can readily be secured in kilns having high velocity of circulation, it does not necessarily follow that they can be duplicated under all conditions.

TABLE 25.—*Average drying time for 1-inch stock kiln-dried green from the saw to 5 per cent moisture content*

Species of wood	Original moisture content	Drying time	Species of wood	Original moisture content	Drying time
	Per cent	*Days*		*Per cent*	*Days*
Yellow birch	80	14–19	Oak, red, or white:[1]		
Red gum, flat-sawed	100	18–24	Northern highland stock	80	20–24
Sap gum	100	12–16	Northern lowland stock	80	24–30
Mahogany	80	10–12	Southern highland stock	80	24–30
Sugar maple	80	15–22	Southern lowland stock	80	32–37
Black walnut	80	20–24			

[1] Plain sawed only; quarter sawed dried under the same schedule takes about one-third longer.

Maple last blocks can be dried in about 60 days, and walnut gunstock blanks in about the same length of time. Heavy oak wagon stock takes from one and one-half to two months per inch of thickness to dry down to 15 per cent moisture content. The common drying times for 1-inch softwoods, such as Douglas fir, the southern yellow pines, and the white pines, run from two to four days, with ex-

ceptions in both directions. Quarter-sawed stock usually may take a more severe schedule than plain sawed, a fact which makes up for some of its natural slowness in drying.

FINAL MOISTURE CONTENT

The moisture content of lumber at the time the lumber is remanufactured or is put into use largely determines the serviceability of the finished product and the satisfaction derived from its quality. A costly table made with some parts having 5 per cent moisture content and others 15 or 20 per cent is almost certain to suffer severe damage from swelling of the dry pieces and shrinking of the wet ones during the process of moisture adjustment that must take place after assembly. Similar and equally unnecessary irregularities in house lumber often are the cause of cracked plaster and of immoveable or rattling windows and doors; these irregularities, however, are usually much greater in such lumber than in furniture stock. The degree of uniformity of final moisture content in the rough material determines the value of the finished product fully as much as the workmanship or as the species of wood; it is a part of the quality of that material. Since a faulty moisture condition of the rough lumber can ruin the finest product of the best plant and of the most skilled workmen, all phases of the matter are well worth the closest study.

FACTORS INFLUENCING FINAL MOISTURE CONTENT

In considering the final moisture content of a given lot of material, it is necessary to think of (1) the average moisture content of the entire lot, (2) the moisture gradient in each piece, and (3) the range in average moisture content of the individual pieces. Variations (*a*) in the initial moisture content of these pieces, (*b*) in their drying characteristics, and (*c*) in the uniformity of the temperature and the humidity throughout the kiln, all tend to prevent a uniform final moisture content. Hence the type of drying schedule and the manner of its application may have an important bearing upon the uniformity of dryness in the product.

SOFTWOODS

With softwoods, a very large percentage of the lumber is kiln dried at the mill. Sometimes the stock is machined immediately after it has been taken from the kiln, but common practice is to bulk pile the rough-dry stock in unheated sheds before machining it. Low grades of rough kiln-dried softwoods are sometimes bulk piled in the open.

Extensive tests recently made in all of the principal softwood producing regions show that the moisture content of kiln-dried softwood lumber as shipped from the mill has a wide range and that, with the exception of one or two individual mills, there is not much difference in this respect among the various regions.

Excepting common grades, only a small number of the boards of an average shipment, usually less than one-tenth of the total, have a moisture content above 15 per cent. The moisture content of the great bulk of such a shipment is between 5 and 15 per cent, with that of a

small portion, about one-twentieth, less than 5 per cent. The moisture range in such stock as it comes from the kiln is probably somewhat greater than this, and the range in common grades is still greater. The degree of uniformity of final moisture content can be increased by holding the stock in the kiln an additional 12 to 24 hours after the desired average dry moisture content has been reached. The final temperature and humidity conditions of the drying schedule should be maintained during this period.

HARDWOODS

In hardwoods the corresponding general situation is somewhat different. The largest part of such stock is air-dried before it enters the kiln and thus much of the inequality in initial moisture content is removed. The amount of drying done in the kiln represents merely the taking away of a comparatively small percentage of moisture, the drying is done quite slowly in comparison with that of softwoods, and the final moisture content is usually fairly low. All these factors contribute to uniformity of final moisture content. No adequate data are available; yet it is almost certain that the final moisture content in kiln-dried hardwoods is more uniform than that in kiln-dried softwoods.

TOLERANCES IN MOISTURE CONTENT

As a result of the entire situation just outlined, the term "average moisture content," which appears in the paragraph on the factors influencing final moisture content, has much more significance for hardwoods, and also for softwoods redried at the consumer's plant, than for softwoods dried at the producer's mill. Although it is difficult, under present conditions, to have softwood stock kiln dried at the mills to a uniform specified moisture content, the average moisture content of individual hardwood and of redried softwood boards may undoubtedly be made to conform quite closely to the average value specified for the lot. In any event, it is highly desirable that at the time of initial use or of remanufacture the moisture content of every piece of wood be very close to that which it will normally reach in service. The exact relation between these two values depends upon the final requirements. Softwood factory lumber that has comparatively slight shrinkage characteristics may show quite a range in moisture content, both in the average value of a lot and among individual pieces, and still be suitable for use in millwork. Hardwood furniture stock should at the time of manufacture be slightly drier than the equilibrium moisture content in service. Stock for gluing should be still drier, as should also stock intended to swell slightly in service, and stock to be stored in an unheated space for some time between drying and final use must be so dry that the absorption of moisture during the time of storage will not unfit it for the service intended.

In general, wood used indoors becomes drier than that used outdoors, and this fact is largely responsible for the differences in final moisture content given in Table 27.

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MEAN RELATIVE HUMIDITIES

A study of the weather reports for various parts of the country shows that the average atmospheric temperature and humidity conditions vary greatly in different regions and that they also have important seasonal variations in each place. The mean relative humidities for a number of cities are presented in Table 26 to exhibit these variations. Unfortunately, converting mean relative humidities directly into equilibrium moisture content is impossible, so that the chief value of this table lies in the general survey it offers.

TABLE 26.—*Mean relative humidities at various points in the United States*

City	Mean relative humidity in per cent				
	Winter	Spring	Summer	Fall	Annual
Cleveland, Ohio	77	72	70	74	73
Denver, Colo	54	51	49	46	50
El Paso, Tex	45	27	41	46	40
Galveston, Tex	84	82	79	78	81
Madison, Wis	82	80	71	75	74
Memphis, Tenn	74	69	75	71	72
New Orleans, La	79	75	78	77	77
New York, N. Y	73	70	74	75	73
Pensacola, Fla	80	77	79	75	78
Phoenix, Ariz	47	32	32	41	38
Portland, Oreg	84	72	67	79	75
San Diego, Calif	74	78	81	78	78
Spokane, Wash	82	61	47	67	64
Wilmington, N. C	78	78	83	81	80

SPECIFIC FINAL MOISTURE-CONTENT VALUES

While it is hardly possible to lay down inflexible rules for proper final moisture content, the information in Table 27, which is based on average conditions in the East and in the Middle West, may serve as a guide in the drying of stock for specific purposes.

TABLE 27.—*Final moisture content desired for wood for various purposes*

Kind of stock	Final moisture content	Kind of stock	Final moisture content
	Per cent		*Per cent*
Furniture	5–7	Vehicle wheel and box parts	8
Musical instruments	5–7	Vehicle stock, except wheel and box parts	15–18
Interior woodwork	6–8	Aircraft	8–12
Softwoods for long freight shipments	12 or less.	Miscellaneous outdoor material	12
Gunstocks	6–8		
Outdoor sporting goods (bats, golf sticks, tennis rackets, polo mallets, etc.)	10		

STEAMING SAP GUM

Some mills make a practice of steaming sap gum before putting it out in the yard to dry. Such steaming serves a double purpose. It sterilizes the stock, killing all fungous spores and any insects or larvæ present, and it contributes to rapid surface drying of the stock after the removal to the air, thus reducing the hazard of reinfection.

In addition, it changes the color of the stock from white to pink, which is desired by some consumers. In patent steaming cylinders the period of steaming varies from 30 to 45 minutes and in specially built steam boxes from 4 to 24 hours; the temperatures in the boxes reach 180° to 212° F. Live steam is used in the cylinder, and a gauge on the supply line indicates pressures up to 20 pounds per square inch, but the pressure and the temperature within the cylinder itself are not known definitely. In the boxes either live or exhaust steam may be used. High temperatures seem to cause checking in any red gum present with the sap gum, but below 180° F. such checking is less common. Two hours of steaming at 180° is probably sufficient to kill all fungi and all larvae of insects. For the purposes of seasoning, a 4-hour steaming period at 180° F. seems to be as good as 8 hours or longer, provided the stock is properly handled after it leaves the steam box.

With sap gum up to six quarter inches in thickness, the doors should be opened immediately after the steaming, and as soon as the stock can be handled it should be pulled out and allowed to cool in the open for at least 48 hours before being bulk piled on the lumber buggies or the trucks that take it to the yard. This treatment is too severe for 8/4-inch sap gum and for plain-sawed red gum of all thicknesses above four quarter inch, since it is apt to cause surface checking. Such stock should be allowed to cool in the kiln or other steaming chamber to about 140° F. before the doors are opened; in other respects, it is handled as just indicated. Distortion can easily be avoided by careful piling.

Rapid cooling dries the surface of the lumber, and if the evaporated moisture is carried away quickly the surface will be dried below the critical point (the lowest moisture content at which fungi can develop) sufficiently to prevent reinfection by the spores of the stain organism, which are always present in the air. When the cooled stock is taken from the kiln trucks it should be run out to the yard and repiled with as little delay as possible. If it is allowed to stand bulk piled on the lumber buggies for several hours after being removed from the kiln trucks, the surface of each piece will retain the moisture flowing to it from the interior of the piece, and consequently the beneficial effect on surface drying that should result from the steaming process will virtually be lost. Such remoistening of the surface is probably responsible for some of the blue or brown spots that are seen on steamed sap gum during subsequent yard drying. In other instances the spotting probably develops because the surface never became sufficiently dry after steaming; this is likely to be the case if stock is pulled from the steaming chamber on a damp day or if the kiln trucks stand so close together while the stock is cooling that the evaporated moisture can not be carried away rapidly.

SEASONING SPECIFICATIONS

MOISTURE CONTENT

Many of the disputes over trouble experienced in the use of lumber are caused by a difference of opinion over the meaning of broad and loose terms common in the trade, such for instance as "kiln-dried"

and "air-dried," or even "thoroughly kiln-dried" and "thoroughly air-dried." These terms are so indefinite that they really are without significance. Unfortunately there are at present no universally accepted standard moisture specifications, so that each purchaser must draw his own. The moisture clause in a seasoning specification is fully as important as a grade specification—sometimes much more important. For many reasons it is essential that the purchaser know certainly that he is getting stock dried to the degree proper for his needs. The vendor also should know positively, and at the very beginning of the transaction, what the purchaser wants. Accurate specifications, expressed clearly and definitely, are of high value to all concerned.

DRYING STRESSES

Although specifying the amount of moisture that purchased stock should contain either at the time of shipment or on receipt is excellent in every way, it is not always sufficient, since the seasoning condition of two lots of similar material dried to the same average moisture content may be vastly different. A workable seasoning specification will contain a clause, based upon the use of stress sections, covering drying stresses in the rough stock. In explicit form such a clause, even if only reasonably complete and only commercially accurate, may be unduly long and cumbersome. A simple statement that the wood shall be free from injurious drying stresses, however, although very broad will still afford reasonable protection to both purchaser and vendor especially when inspection by means of stress sections is definitely permitted. In fairness to the vendor, information about the probable uses of the stock, expressed more or less briefly, should be included.

STORAGE OF KILN-DRIED STOCK

Since all of the pieces in the kiln are not of the same moisture content at the end of the drying period, it is desirable that they be held in storage until both the dry and the less dry ones approach closely an identical moisture content. The time required for such storage varies with conditions. One week is considered long enough for furniture stock, and two weeks are specified for aircraft stock. Careful conditioning in the kiln reduces the time desirable in storage.

Dimension stock and finished wood products that have to be stored should be held in proper atmospheric conditions, for otherwise they will absorb or will lose too much moisture. Later, when the stock has been remanufactured and is in actual use, this gain or loss may damage its serviceability.

When dry stock is bulk piled in a damp storeroom, the exposed ends of the boards pick up moisture rapidly, the exposed edges and sides do so more slowly, and absorption in the interior of the pile is quite slow. As a result of this situation the moisture content of the entire pile will gradually become too high and, further, the moisture distribution in individual pieces and the moisture range among different ones will be unsatisfactory. Short stock, with exposed end surfaces, is very liable to trouble resulting from storage in damp or unheated storerooms.

Storerooms need only a little heat to make them dry enough for most dry-wood storage. All that is required is sufficient rise in temperature to bring the humidity down to 25 to 40 per cent, and ordinarily a temperature of about 30° F. above the outside atmosphere is enough. Assume, for instance, that it is desired to store flooring stock at 6 per cent moisture content and that the outside temperature and humidity are, respectively, 35° F. and 90 per cent. At 65° to 70° F., a humidity of 28 per cent corresponds to a moisture content of 6 per cent, and if the 35°-90-per-cent atmosphere is warmed to 67° F. its humidity will be the desired 28 per cent. (See also "Relieving casehardening during storage" on p. 42.

MOISTURE CHANGE IN TRANSIT

Studies on carload shipments of western yellow pine from the Inland Empire [2] and of Douglas fir from Oregon, all to the Chicago territory more than halfway across the continent, have shown that the moisture change in transit is negligible when the stock is shipped in tight box cars. With kiln-dried boards averaging 8 per cent moisture content, the average change in moisture was only 0.2 per cent. In a car of molding the change was 0.8 per cent. Similar data are not available for hardwoods, but no greater change should be expected.

TYPES OF KILNS

Dry kilns for wood are of many forms and of varied types, and accordingly they can be classified in several ways. For the purpose of describing both their construction and their operation they have been divided in this publication into two groups, namely, progressive and compartment. Progressive kilns are sometimes called "continuous," and compartment kilns are known also as "box" and as "charge." The essential differences between the two types are the result of the methods of handling the stock through them. In the progressive kiln (fig. 9), a number of truck loads of lumber, extending through the kiln in an unbroken line and all in different stages of drying, make up the total charge. Comparatively small amounts of stock are periodically fed in at the receiving end, each load in effect pushing along the trucks ahead of it and at its entry forcing out a load occupying equal track space at the discharge end. The stock thus moves progressively through the kiln until it emerges, supposedly dry, after a specified time of continuous drying under the various conditions of the long kiln. In the compartment class, on the other hand, the kiln is loaded fully at one time, the entire charge remaining in place throughout the drying period. Again, in the progressive kiln the temperature and the humidity at any point are intended to remain constant, but the kiln is hotter and drier at the dry end than at the green end; in contrast, the temperature and the humidity are as nearly uniform as possible throughout the compartment kiln at any given time, and, although in it these conditions usually are changed from time to time as the stock dries, for certain classes of drying they are kept constant throughout the drying

[2] The wooded basin lying in northwestern Montana, Idaho north of the Salmon River, Washington east of the Cascade Mountains, and the northeastern tip of Oregon.

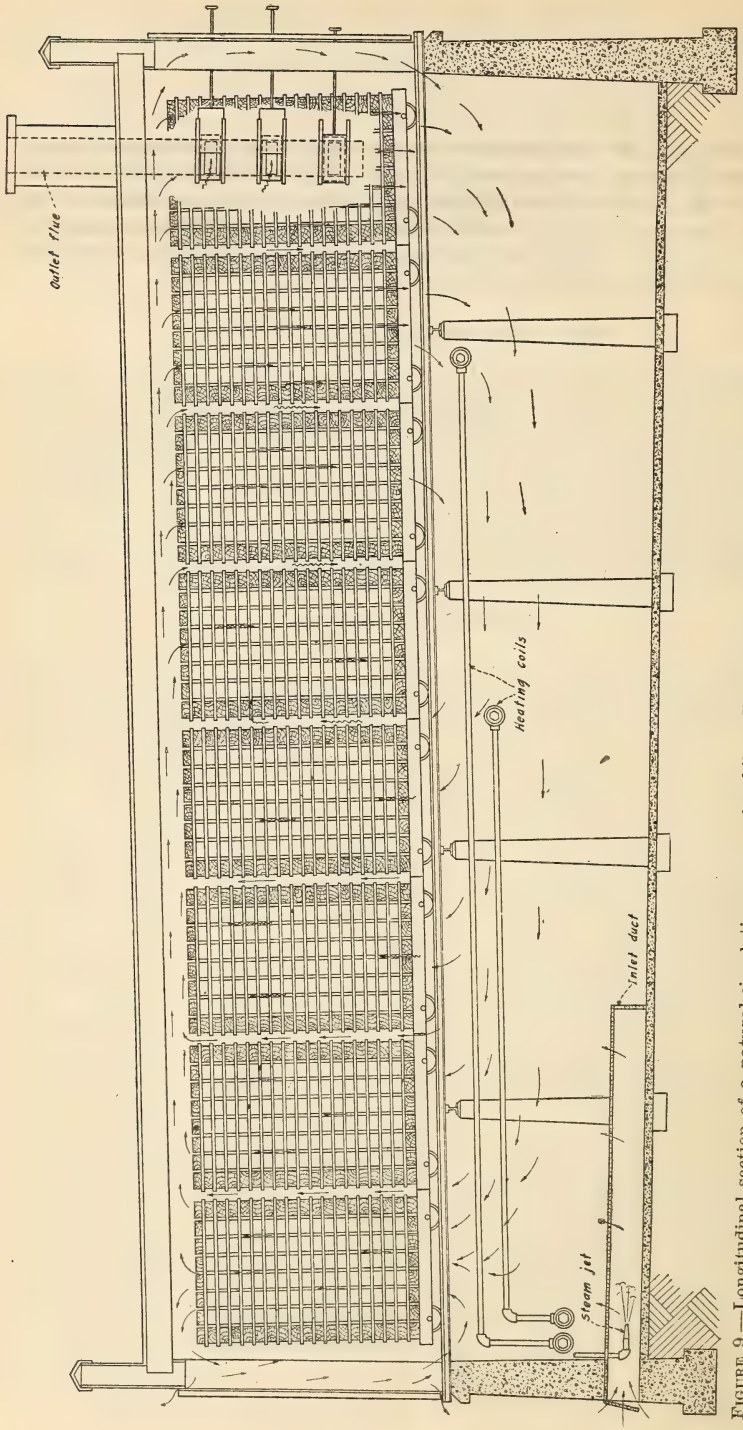


FIGURE 9.—Longitudinal section of a natural-circulation progressive kiln. The lumber moves from right to left, whereas the main longitudinal air circulation above the rail level is in the reverse direction. In addition there are local currents of air up and down through the lumber, as indicated by the arrows; the wavy arrows indicate sluggish air movement. The cooling effect of each door produces local downward circulation at the extreme ends of the kiln

period. Since the temperature and the humidity in a progressive kiln vary from end to end, the circulation of air must be chiefly longitudinal; the circulation in a compartment kiln may be in almost any desired direction but is usually some kind of cross circulation.

The field of the progressive kiln is limited, whereas the compartment kiln can be used for almost any kind of drying. The progressive kiln must be supplied continuously with lumber of the same kind and thickness if it is to function properly, and it, therefore, is not satisfactory except where a constant supply of such stock is available; further, because of the lack of flexibility of control of temperature and humidity it is not adapted to drying requiring great accuracy of control. High-humidity schedules, oscillating schedules, and constant-temperature-and-humidity schedules can not be followed satisfactorily in progressive kilns, nor can steaming treatments be given effectively.

The economy in steam consumption of progressive kilns is often very high in comparison with that of compartment kilns doing similar drying.

PROGRESSIVE KILNS

Progressive kilns may be of several different types, roughly classed as natural circulation and as forced circulation. Most natural-circulation kilns rely almost entirely upon differences in temperature to produce the circulation, whereas forced-circulation kilns rely largely upon centrifugal blowers, disk fans, or steam-jet blowers for that purpose. The progressive kilns now in service are mostly of the natural-circulation type.

In all progressive kilns the major portion of the circulation is longitudinal; the air flows through the lumber from the warm, dry end to the cool, moist end. It may be discharged into the atmosphere from the cool end, or it may be returned to the dry end through suitable ducts or passages.

As the air progresses through the kiln from the dry end to the green end it becomes cooler and more moist, the cooling itself increasing the relative humidity and the moisture evaporated from the wood adding a share. Thus the severity of its drying action is automatically reduced as the air reaches the greener lumber. The extent of this reduction depends upon the individual kiln design, upon outside atmospheric conditions, and upon the kind, the thickness, and the initial moisture content of the stock being dried. Other conditions remaining constant, the longer the kiln the cooler and the more moist will be the air at the green end. Similarly very wet, easily dried stock or a reduction of heating surface at the green end will certainly cool and moisten the air more than the usual conditions, and a reduction in the rate of circulation may do so. To adjust conditions so that the temperature and the humidity will be in accordance with the drying schedule throughout the length of the kiln is usually very difficult, since ordinarily only a single point of control is possible for each of these two factors. The controls for temperature and humidity may be located at the same end of the kiln or at opposite ends, as seems best in individual circumstances. Occasionally steam jets are fitted along the length of the kiln to increase further the growing humidity as the air moves toward the

green end, and in some kilns vents are provided along the length so that some of the air can be exhausted before it reaches the green end. There is seldom any provision, however, for regulating the temperature along the length of the kiln.

NATURAL-CIRCULATION PROGRESSIVE KILNS

The circulation in natural-circulation progressive kilns is very complex. In the commonest kind of such kilns it is made up of (1) longitudinal outside circulation (see "Air circulation in the kiln," p. 26) from the intakes at the dry end to the exhaust flues at the green end, (2) longitudinal recirculation from the dry end to the green end above the heating coils and in the reverse direction below them, and (3) cross recirculation, mostly vertical, through and around each pile. The longitudinal circulation takes place largely in the passages between the inner face of the kiln and the piles instead of through the piles, so that much of the actual drying is done by the widespread vertical recirculation. The longitudinal circulation serves chiefly to maintain the temperature and the humidity gradients and to remove much of the moisture from the kiln.

The various kiln manufacturers employ a number of different arrangements of intake ducts and exhaust flues. In the most common one, intakes are provided at the dry end and outlets at the green end. In another, no intake openings are provided, and exhaust flues are located in one or more rows the entire length of the kiln.

Although a chamber for preliminary steaming can be formed in many natural-circulation progressive kilns by dropping a curtain between two trucks near the green end, steaming in such a curtained-off space is apt to upset the conditions in the kiln, increasing the humidity throughout. Furthermore, trouble may result if stock warmed in this manner is not carefully cooled in saturated air to the drying temperature before the curtain is rolled up and drying is begun.

FORCED-CIRCULATION PROGRESSIVE KILNS

Where the longitudinal circulation in a progressive kiln is stimulated by steam-jet blowers, they are usually placed near the dry end of the kiln, pointing toward the opposite end, and may be so arranged that they can draw fresh air from the outside as well as recirculate the air within the kiln. Many arrangements of disk and centrifugal fans are possible, and various ones have been tried out from time to time. At present the most favored arrangement seems to be a pair of large disk fans in the end wall of the kiln, at the green end. The air drawn through the kiln by the fans may be discharged to the atmosphere or returned to the dry end through suitable ducts, depending upon the design of the kiln. It should be pointed out here that the gradients of temperature and humidity along the length of the kiln depend, among other things, upon the rate of circulation, and a marked increase in that rate will reduce these gradients very materially.

NATURAL-CIRCULATION COMPARTMENT KILNS

Although natural-circulation compartment kilns differ considerably in detail design, most of them are arranged for cross circulation;

the fresh air is usually brought in at the bottom and distributed throughout the length of the kiln by means of ducts under the charge of lumber. Vertical ventilating flues, with the outlets to them leaving the kiln at various heights and in various ways, are commonly provided at intervals along both sides of the kiln. All

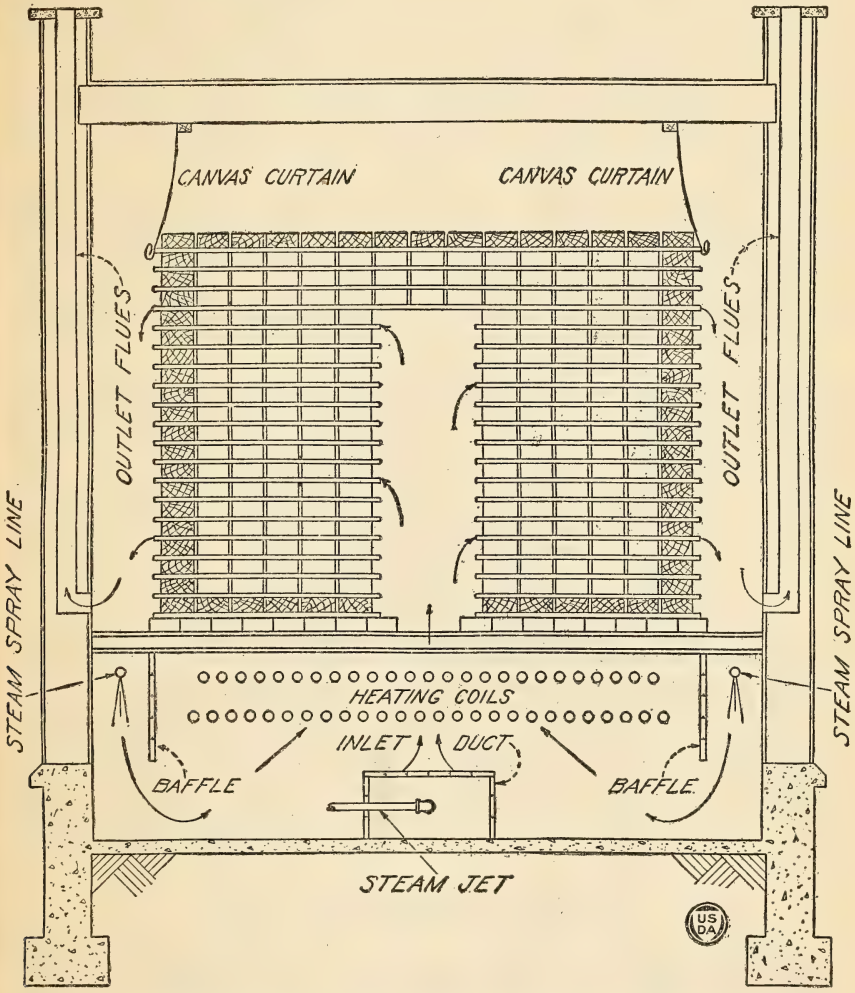


FIGURE 10.—Cross section of a natural-circulation compartment kiln. The arrows indicate the direction of the main circulation, which is crosswise. Air, heated by the coils, passes up through the central chimney and sidewise through the end-piled stock, accumulating moisture in its movement through the lumber pile. Most of the moisture-laden air drops down between the walls and the baffles, returning then to the heating coils, but some of it is discharged through the outlet flues. Fresh, comparatively dry air, drawn through the inlet duct, replaces the moist air discharged. Continuous recirculation and outside circulation of this nature are essential to satisfactory operation of the kiln

parts of the flue arrangement, however, depend upon the diverse ideas of the individual manufacturers; commercial practice includes, for instance, the entire possible range of locations for the outlets, at

least one manufacturer drawing the exhaust air from below the lumber, practically at the kiln floor, and another placing every one of the air vents in the roof and the flue for each directly above it. Almost as wide a range is found in the location of the inlets to the kiln; although the air is usually brought into the kiln in ducts running along the floor, several kiln designers carry it up in risers at various points along the length of the kiln and deliver it at convenient heights above the rail level. While it is customary to provide considerable outlet flue area, there is a wide difference in the amount of inlet area. One maker furnishes none at all, another allows about a square foot for a kiln 70 feet long, and a third insists upon at least 4 or 5 square feet for a similar kiln only 40 feet long.

The natural-circulation compartment kiln must depend very largely upon recirculation to effect the drying, and in well-designed kilns of this type the recirculation is much greater than the outside circulation through inlets and chimneys. Figure 10 shows the general construction of such a kiln; the figure, which is a composite, represents no particular make.

The principles of the action of this kiln can best be understood by following the arrows in Figure 10 that indicate the air flow. As already explained under "Air circulation in the kiln," circulation is produced by differences in the temperature of the air in the kiln. Fresh, cool air enters the kiln through openings in the inlet duct, passing over the heating coils and into the space left for the purpose in the center of the lumber pile, and thence outward and downward. Some is exhausted through the outlets, but most of it returns past the steam-spray line and the baffles to the heating coils and then starts around again. The downward-pointing steam sprays, which are used both for steaming treatments and for humidity control, are placed so as to assist the recirculation as much as possible. In addition, the baffles tend to prevent the air from rising in any passages, except the one, often called a chimney, within the charge, thus assisting materially in producing and in maintaining the desired air flow. They also keep the steam from spraying against the lumber or the heating pipes. The floor boards under the lumber pile protect the lower layers from direct radiation, besides preventing the short-circuiting of the legitimate air paths by the passages through these layers.

CONDENSER COMPARTMENT KILNS

Condenser kilns as now built are usually of the recirculating type without air inlets or outlets. A single row of condenser coils is placed high on one side of the kiln, or one row on each side. Cold water is supplied to the coils, and the moisture condensed on them from the kiln atmosphere is drained from the kiln through suitable troughs.

WATER-SPRAY COMPARTMENT KILNS

Water sprays in compartment kilns, located about the same as the steam-spray lines in Figure 10, serve the dual purpose of stimulating circulation and of controlling humidity. The control of humidity is accomplished by regulating the temperature of the spray water.

The air, in its passage through the sprays, is cooled to a predetermined temperature (the dew point corresponding to the desired temperature and humidity), emerging from its conditioning bath in a state of saturation. Then after being reheated to the kiln temperature the air again passes through the lumber, following the general path indicated in Figure 10.

EXTERNAL-BLOWER COMPARTMENT KILNS

External-blower kilns for drying lumber, almost without exception, are of the recirculating compartment type. Figure 11, a diagrammatical cross section of such a kiln, illustrates the path of the air through the system. The blower, which is usually placed in an operating room adjoining one end of the kiln, exhausts and returns the air through a duct system running the full length of the kiln. The heating units may be boxed in at the blower, or they may be arranged in almost any desired manner in the kiln proper. The humidity may be increased by means of steam-spray lines located along the sides of the kiln, much as in Figure 10, or by means of a steam jet in one of the ducts; it may be reduced by opening a fresh-air intake located about as shown in Figure 11. Under most conditions no air outlets are needed, since leakage, aided by the air pressure within the kiln, will normally take care of an amount of air equal to that drawn in through the fresh-air intake. For species of wood that give up their moisture very readily, however, it is sometimes necessary to provide air-outlet flues in order to make possible keeping the humidity down to the desired point.

INTERNAL-FAN COMPARTMENT KILNS

Internal-fan kilns as built in this country are almost exclusively of the recirculating compartment type with cross circulation. Nevertheless a number of such kilns, designed for particular purposes, have special fans or special blowers for producing a definite longitudinal circulation in addition to the cross circulation. One European manufacturer has developed a line of internal-fan kilns that includes a progressive type.

Figure 12 is a diagrammatic sketch of a cross section of an internal-fan kiln. The disk fans outlined are mounted at intervals of perhaps 6 to 8 feet upon a line shaft which, extending the full length of the kiln and projecting into the operating room, is driven by motor or engine in this outside room. Each fan has a separate housing, designed to permit flow of air to the fan from the sides and discharge of the air upward from the fan into the central chimney. Reversal of the direction of rotation of the shaft causes reversal in the direction of air flow, the central duct then becoming the intake for the fans and the lateral ducts carrying their discharge. Occasional reversal of the circulation helps to smooth out differences in the drying rate, especially differences between the entering-air and the leaving-air portions of the pile. The heating coils and the distributors in turn, as the air flow is reversed, break up the blast from each fan, spreading out the air column so as to give a reasonably uniform circulation throughout the lumber piles; to a certain extent the layers

of lumber themselves equalize the various rates of flow in the air as it reaches them. Two sets of steam spray lines may be provided, as shown, one set for use with outward circulation and the other for

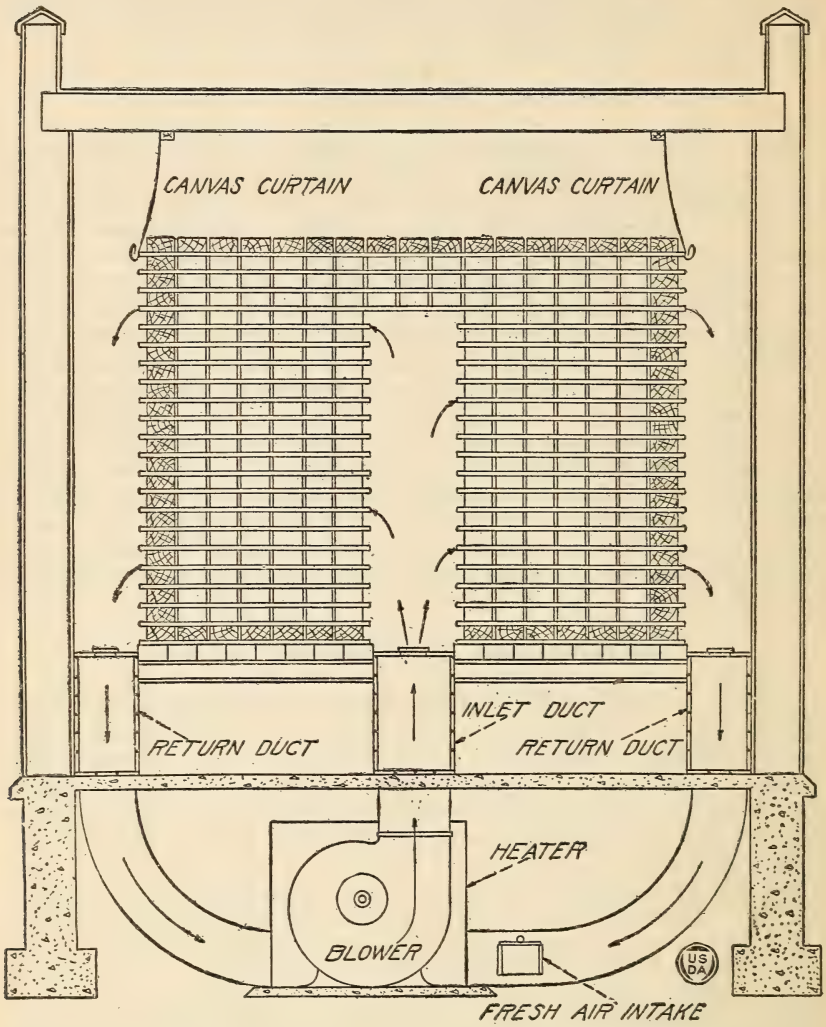


FIGURE 11.—Cross section of a typical external-blower compartment kiln. The blower, drawing air over the heating coils, forces a current of air upward through the inlet duct and the chimney, through the kiln charge, as indicated by the arrows, downward into the return ducts, and then to the heating coils. Supplying some air from the intake reduces the humidity in the kiln, since the fresh air replaces moisture-laden air that ordinarily escapes through leakage; exhaust flues, however, are necessary with rapid drying rates

inward. Since the circulation-producing effect of the steam jets is not needed, however, a simpler arrangement with a single steam line running along the bottom of the kiln near the center and a single jet located at each fan has been developed.

While it is obvious that many arrangements of fans and of heating systems are possible, American manufacturers employ only the one illustrated, namely, a single central fan shaft and heating coils on each side, all located below the lumber. A German type recently introduced in the United States has a similar arrangement of fan shaft and of coils, but all this equipment is placed above the lumber.

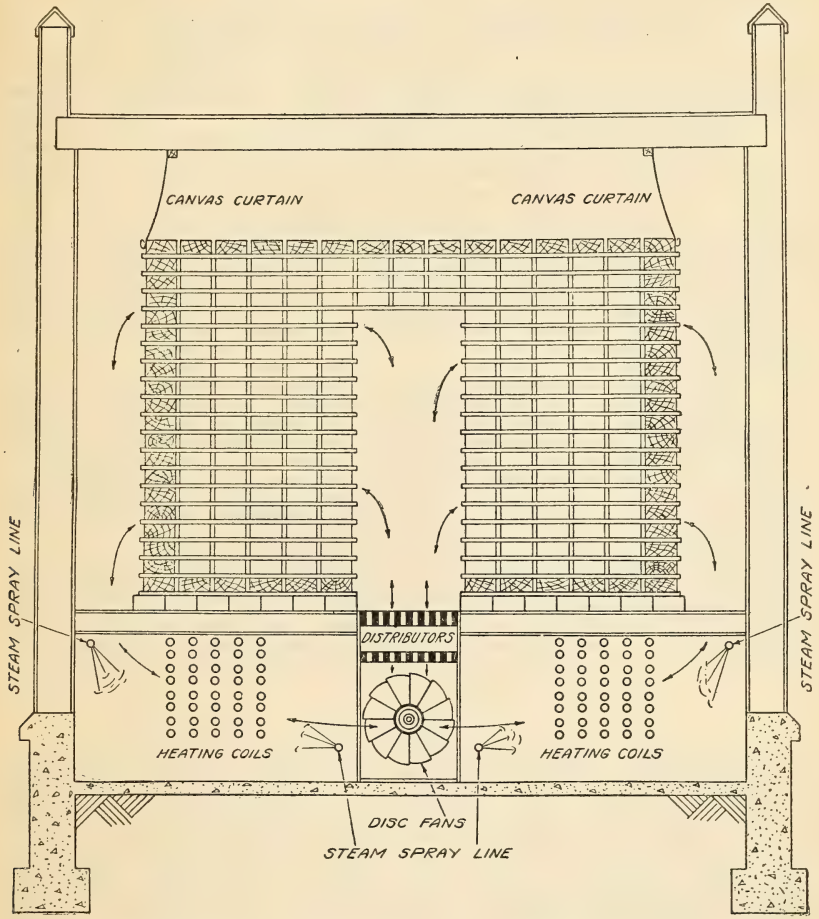


FIGURE 12.—Cross section of a typical internal-fan kiln. The chief part of the circulation is crosswise, in the direction of the arrows. A series of disk fans, mounted with a spacing of 6 to 8 feet on a shaft that extends the full-length of the kiln, draws air over the heating coils and forces it upward through distributors that also exend the length of the kiln. The direction of air circulation may be reversed by reversing the direction of rotation of the fans. In several commercial designs the distributors are dispensed with, the lumber itself and the heating pipes being relied upon to distribute the air

SUPERHEATED-STEAM COMPARTMENT KILNS

The superheated-team kiln is comparatively simple. The essentials of its construction and operation are merely these: Provision must be made for high-pressure steam for the heating coils and the

jets, the circulation should be reversed periodically, and the design must secure short travel of the steam through the lumber.

Two types of superheated-steam kilns were developed and marketed several years ago. In one the heating coils and the steam-jet lines are under the lumber piles. In the other the heating coils are on the side walls and the steam-jet lines, four in all, are located above and below the coils.

PILING LUMBER FOR KILN DRYING

Lumber to be kiln dried is usually piled in layers with several narow strips, called either stickers or crossers, between adjacent layers—the layers are also called courses. Sometimes short stock, like spoke billets, handles, and shoe-last blocks, is simply dumped into the kiln without any attempt at orderly arrangement. This method, however, is likely to cause irregular drying unless small amounts only are dried at a time. The piling and the stickering of the lumber should provide suitable air passages around the surfaces of each piece in the charge, and should furnish sufficient support to the lumber, with whatever restraint is necessary, to make it dry as straight as possible.

For drying in a progressive kiln, the lumber is always loaded on trucks, or bunks, and is run through the kiln on rails; the track is usually pitched downward, so that gravity will assist in moving the loads toward the dry end. Similarly, large compartment kilns are usually provided with rails, to permit running the lumber in on trucks, but many small kilns have no such provisions, and in them the lumber is piled on horses or equivalent supports.

The two general ways of piling lumber are called, respectively, horizontal or flat piling and vertical or edge piling. Each of these may be divided into cross and end piling. (Pl. 15, A and B.) In cross piling, the boards run across the kiln, and in end piling they run along it.

FLAT PILING

The manner of piling must be adapted to the characteristics of the kiln. The design of the forced-circulation type more or less limits the form of piling suitable for it. In natural-circulation compartment kilns having heating coils running lengthwise of the kiln, the lateral circulation that occurs is generally in the plane of the cross-section; end piling is best fitted for this condition, since with that method the air moves parallel to the stickers. If cross piling is used with cross circulation the stickers, which are then at right angles to the movement of the air, practically block the circulation and hence extra-wide spacing between adjacent boards or pieces in each layer must be maintained if satisfactory results are to be secured. In those compartment kilns, however, in which an individual heating coil crosswise of the kiln is provided for each pile, cross piling is required.

CIRCULATION

The circulation in natural-circulation progressive kilns is complex, so that obtaining a general longitudinal movement of air through the lumber piles is difficult if not impossible. A large but variable part

of the air movement that does exist, longitudinal included, is local in character and to a great extent is independent of the direction of piling. Hence considered from the circulation standpoint there is little to choose between end piling and cross piling; both systems are employed with success. In comparatively long kilns for drying green softwoods, however, end piling seems to permit the securing of a somewhat better local circulation, especially if the heating system and other detail parts of the kiln are arranged with this purpose in view. Cross-piled progressive kilns are designed to take a definite maximum length of stock, making it especially desirable to have all the piles in such kilns take up fully the space intended for them, in order to allow as little opportunity as possible for the development of air currents that counteract the regular air movement.

SPACING OF BOARDS

As already suggested, the spacing of the boards or pieces in the individual layers of the piles has an important bearing upon circulation, especially in natural-circulation kilns; manufacturers of this type frequently recommend a wide spacing. The amount of space to leave in any particular case, depending as it does upon the circulation, is a matter of judgment. Ordinarily 2 to 3 inches of open space to each 12 inches of stock width is sufficient for slow-drying species, but for fast-drying stock 4 to 6 inches is desirable. One space of 2 inches is better than two spaces of 1 inch, but the distance between spaces should not be over 14 inches. In piling narrow stock it is desirable to group the boards in widths of 10 to 12 inches with 2-inch spaces (or more) between the groups. In so far as possible, spaces in successive layers should be in vertical alignment. To obtain best results, material dried at the same time should be of the same species and the same thickness and with its moisture content as nearly uniform as circumstances permit. Stock in the same layer should be of one thickness, since otherwise warping will develop in thin boards.

STICKERS

Stickers should be made from clear, straight-grained stock, entirely free from both stain and decay, and should be dressed to a uniform thickness. Seven-eighths-inch stickers are common for most classes of stock, except in edge stacking, in which the requirements of the stacking machine may determine both their width and their thickness. If stickers are made about one and one-half times as wide as they are thick, they will lie flat instead of tending to roll when the boards are laid on them.

SPACING OF STICKERS

The spacing between tiers of stickers should be reasonably close. With green hardwoods it should normally vary from 2 to 4 feet. Softwood practice, which depends somewhat on species and grade, is variable; as a rule the spacing is from 4 to 6 feet, but it has been demonstrated, for southern pine, that a spacing as close as 2 feet results in sufficient saving from lessened warping and consequent kiln and planer degrade to be economically sound practice. Box piling,

which will be described later, ordinarily requires a 2-foot spacing for satisfactory results. If the boards show a tendency to warp, with the spacing employed, the stickers should be placed more closely.

STICKER SUPPORTS

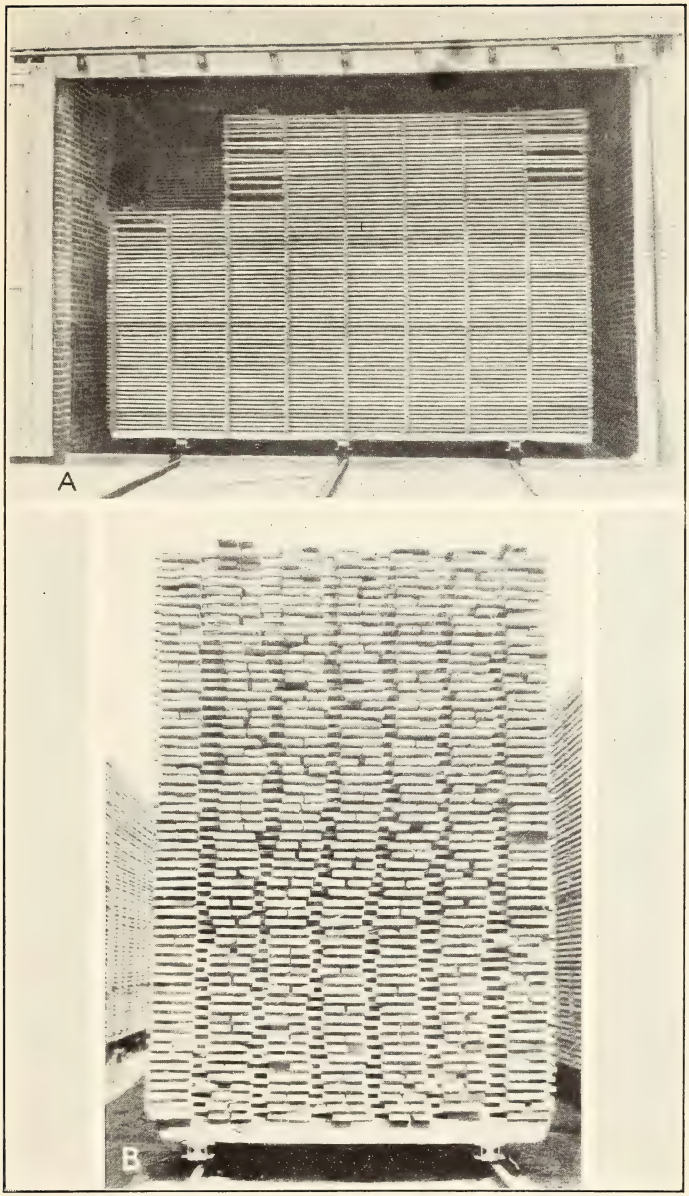
The supports necessary for the tiers of stickers should be firm and even, and when possible one should be directly under each tier. Individual conditions, such for instance as the number of tracks in the kiln, the kind of piling required for the loads, and sometimes the ingenuity of the operator, determine the location of sticker supports. Other individual conditions largely select the material for them; metal often is cheaper than wood, especially in high-temperature kilns, in which wooden sticker supports may have a life of only a few trips through the kiln. Naturally breakage of sticker supports usually occurs in the kiln; it then causes delay and expense in removing the kiln car affected, as well as damage to the stock and sometimes also to the track supports and the heating coils.

ALIGNMENT OF STICKERS

Perfect alignment above their supports of those of the stickers that actually carry the weight of the lumber is essential, since the eccentric loading caused by poor sticker alignment tends to deform the lumber. When the number of sticker tiers exceeds the number of solid supports that can be provided conveniently, two tiers can be started upward from a single support by slanting the pair apart until the desired space between them is secured, and thereafter continuing them vertically—a third tier of course is run straight up as usual, directly over the support. Further, when offset tiers are started thus, especially in the case of a single end tier, enough extra stickers should be placed suitably in the lower part of the pile to extend the vertical section of the sticker line clear down to the lowest layer; these additional stickers are intended to act as separators to prevent warping. If only a single tier is inserted between adjacent supports in the manner outlined, an arching line of stickers should be carried over to it from each support. Figure 13 illustrates good practice in stickering a flat-piled kiln charge having insufficient points of support.

BOX PILING

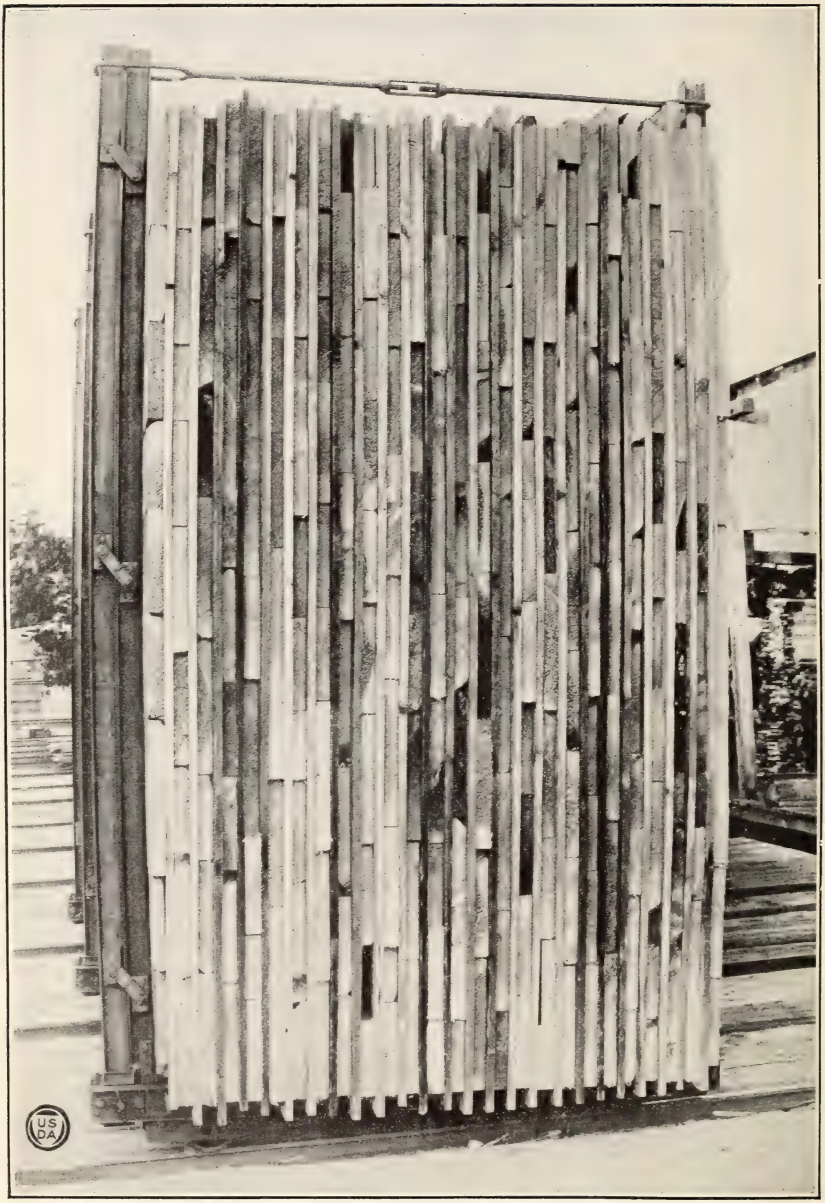
Great care must always be exercised in the actual piling which, on account of the importance of proper stickering, may be said to include the lumber as well as the stickers. Having in each pile boards of only one length is the ideal condition, but where this is impossible the stock should be box piled. In such piling the outer tiers are carried up with full-length boards and the short boards in each layer are brought flush alternately at opposite ends of the pile, although bringing all of them flush at the same end is possible. The alternate method diffuses the chimney effect incident to tiers of short length, both by making the vertical end spaces smaller and by separating them, and thus prevents upsetting the circulation; it avoids the concentration of lumber at one end of the pile, with the unequal and irregular drying that results, and it also obviates the tendency



METHODS OF FLAT PILING KILN TRUCKS

A.—Cross piling.—The careful alignment of boards and of stickers and the adequate number of tiers of stickers in this illustration are admirable. Box piling, with the short lengths inside the outer tiers of full-length boards and staggered from end to end of the pile, however, is preferable to the arrangement shown. Stringers stiff enough to support properly the outside stickers, or the arch stickering of Figure 13, give less degrade than deformed stringers, and the avoidance of overhanging ends of boards also reduce warping.

B.—End piling.—Each tier of stickers is supported by a tie directly under it, all of the boards in each course are of the same thickness, the narrow boards are grouped in pairs, and the sides and ends of the pile are uniform and vertical, all of which is highly desirable. On the other hand, placing the outer stickers at the extreme ends of the boards would reduce both warping and end checking, and uniformity of the vertical air channels through the pile would give faster and more even drying.



VERTICAL CROSS PILING

Crosswise edge stacking for the dry kiln; a truck load of lumber with shrinkage take-up devices

of stickers to sag when they are unsupported for a considerable distance. Both the lumber and the stickers should be arranged so that no board rests on unsupported stickers and no ends are unsupported. Less end checking develops when the stickers are at the extreme ends of the boards than when they are even a few inches back. Minor modifications of the method of piling here described also receive the name "box piling."

EDGE PILING

Under certain conditions vertical or edge piling is cheaper than flat piling. (Pl. 16.) Several automatic stacking and unstacking machines have been developed for this work. While they differ in operation, the resulting stacks are very much alike, except in the width and the thickness of the stickers. The layers of boards and

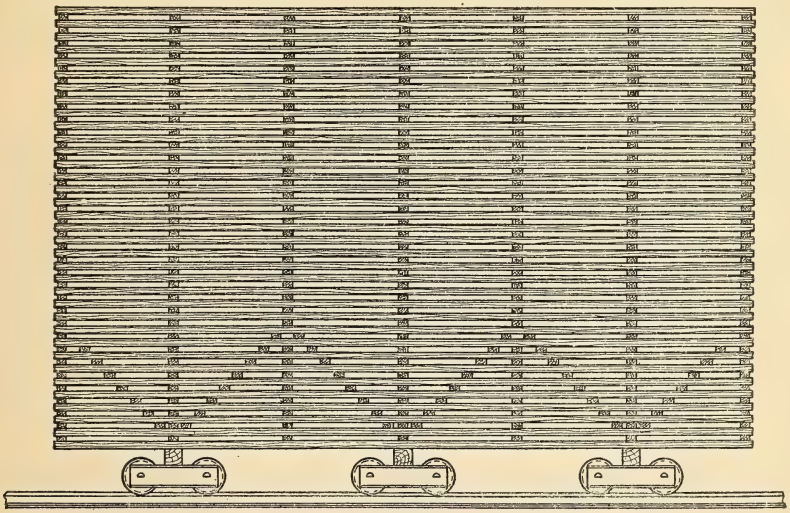


FIGURE 13.—A very effective way of arranging the stickers when the number of rows desirable exceeds the number of supports available. The use of a large number of rows of stickers is recommended wherever there is appreciable degrade from warping or from planer splitting; to secure the greatest benefit from their use it is essential both that the individual rows be given as much support as possible and that the entire load be piled as nearly straight and flat as possible

the stickers are vertical and, in contrast with flat piling, the boards in each layer join closely, without intervening spaces. As the lumber shrinks in drying there is a tendency for the stacks to become loose and to lean. To avoid this trouble several take-ups have been devised; they are intended to squeeze the load together sidewise as the boards shrink and thus keep it always tight. A serious objection to most take-ups is that they increase the weight of the bunk considerably; this is important where the bunks have to be moved by hand.

CIRCULATION

The principal direction of the circulation through the lumber, with edge stacking, must be either upward or downward. Most

blower kilns are designed for downward circulation through the lumber, while in internal-fan kilns the movement of the air may be either upward or downward as the operator chooses. The arrangement of heating coils and of other elements in most natural-circulation kilns tends to produce upward circulation, whereas the evaporation of moisture does the opposite. The preponderance of one over the other determines in large measure the direction that the air actually takes at any given time; when drying green stock it is usually downward during the beginning of the run and upward toward the end, and it generally is upward throughout the final drying of previously air-dried stock. In forced-circulation kilns the effect of evaporation on circulation is largely overshadowed by the effect of the mechanical apparatus.

Considered from the standpoint of circulation the direction of piling of edge stacked stock makes little difference; the circulation must be vertical with either cross piling or end piling. The present tendency is to use end piling and single-track forced-circulation compartment kilns.

STICKERING

With edge stacking as usually practiced only three stickers are used for each layer, and the boards do not receive support enough to prevent warping. Comparable tests made on southern pine lumber showed that flat piling with seven rows of stickers gave substantially less degrade from planer splitting than did edge stacking with only three rows of stickers.

Edge stacking, with the special equipment that makes it profitable, is limited to large softwood operations, principally in the Pacific Northwest and other western lumbering regions. There are, however, a number of installations in the South.

PILING PRACTICE

Both cross piling and end piling are used in natural-circulation progressive kilns. Edge stacking also is employed to a slight extent. Although there seems to be no definite correlation between the method of piling the lumber and the ventilation openings, regardless of how the piles are arranged care must be taken to provide ample space for recirculation through them if good drying is to result. One type of progressive kiln with steam-jet blowers is arranged to force the air through internal ducts from the green end of the kiln back to the dry end. This system can be used with either cross piling or end piling.

End piling is the logical arrangement of lumber in a cross-circulation kiln, but many such kilns, particularly the older ones, are equipped for cross piling. On the other hand, several new types of cross-piled natural-circulation kilns have recently been developed. In them each pile of lumber is arranged, together with the heating coils, the steam spray lines, and the flues, to secure active recirculation of air through the piles; each of these piles has a set of heating coils of its own, also placed crosswise of the kiln. Such recirculation is similar in its general features to that through the pile in Figure 10, though of course its direction is lengthwise of the kiln instead of crosswise.

DETAILS OF KILN OPERATION

The successful operation of dry kilns requires constant and careful attention. The results secured depend to a large degree upon the operator, and he should be impressed with his obligation to make every effort to turn out perfect stock. The first duty of a new operator is to familiarize himself with the kilns under his supervision. Before making the initial run in a kiln, he should inspect it thoroughly to assure himself that the structural work, including the rails, is mechanically safe, that the heating coils, traps, and similar parts are in proper working order, and that the instruments have been calibrated and, after being properly placed in the kiln, have been checked by additional brief comparison with a standard instrument. Efficient care of instruments requires the recording in a log book of all full calibration readings, together with check readings, and brief memorandums of all work done on the instruments.

PERIODIC INSPECTION OF KILN

The kiln building should be kept structurally sound; each part, of course, must be sufficiently strong and rigid for its duty, but in addition the building should be tight, as tight as a good residence. Maintaining the doors in good repair will retain the large amount of heat allowed to escape by poorly fitting ones, usually with a resulting upset of the drying conditions. It is extremely difficult to maintain high humidities in a leaky kiln. Rails and rail supports, together with their fastenings, should be inspected periodically. Proper repair of the pipes is highly important. Besides the usual looking after leaks and other ordinary matters obviously necessary, their pitch to the drain end should be maintained both to allow free flow of the condensate to the traps and drainage of air from the system. The coils should be inspected occasionally to make sure that all of them are working, and the traps should be examined every day. Suitable runways should be provided to enable men entering the kiln to do so with safety and without walking on the pipes. These runways, preferably gratings, must be so arranged that they will not interfere with the air circulation; in general, solid planking should not be used for this purpose. The interior surfaces of the building and also the iron work and the pipes should be protected with a good kiln paint; the pipes, however, can be painted with a mixture of cylinder oil and graphite if this type of protective coating is preferred for them. The latter coating can best be applied when the pipes are hot.

CALIBRATION AND ADJUSTMENT OF INSTRUMENTS

Success in all except the simplest kind of kiln drying and the most easily dried stock depends upon the accuracy of the instruments and of the apparatus used in the regulation of the kiln and in the determination of the moisture content, as well as upon the condition of the kiln, upon the schedule, and upon the operator. It is therefore essential that all of the control equipment be maintained precisely in its correct operating condition. Most important is the calibration and adjustment of temperature indicating, recording, and regulating instruments, since through them both temperature and humidity are determined and also controlled.

THERMOMETERS

STANDARD THERMOMETERS

The easiest and most satisfactory way to calibrate indicating and recording thermometers is to compare them at different temperatures within their ranges with a standardized thermometer, the accuracy of which has been determined by its manufacturer. Hence each operator should have at least one standard indicating thermometer, made by a reliable concern—even good glass shrinks slightly with age, so that thermometers manufactured too hurriedly become inaccurate in time. The type recommended is a 12-inch mercury-filled glass chemical thermometer, with graduations in degrees Fahrenheit etched on the stem, and correct for ordinary purposes over a range of 30° to 220° F. Such a thermometer can be purchased at a list price of about $3, and a brass protecting sleeve, desirable for kiln service, can be had for about $1.50 net.

CALIBRATION OF INDICATING THERMOMETERS

The first step in the usual laboratory method of calibration by comparison with a standard thermometer is the immersion of the standard and the thermometers to be calibrated in a vessel of water, which is constantly stirred to keep the temperature uniform throughout. The water, which should be cold at the start, is gradually heated, and the thermometers are read at intervals of a few degrees throughout their working range. The difference between the readings of the standard and of another thermometer at any temperature is the error of the other one at that temperature; a correction of this amount must be applied to the faulty reading to give the actual temperature. If the standard reads the higher, call the correction plus (+) and add it to the future readings of the other thermometer; if not, subtract it from those readings. This method is applicable to all portable thermometers used in kiln work, including wet-bulb, the wicks of which are removed during the process. Once every six months should be sufficient for the calibration of glass-stem thermometers.

CALIBRATION OF RECORDING THERMOMETERS

Recording thermometers require more attention than other types on account of the comparative ease with which they may become deranged; those used in dry kilns are almost invariably of the extension-tube type. They should be calibrated in water, as described for glass indicating thermometers, the bulb and about a foot of the tube being immersed. Sometimes this calibration can be accomplished by dismounting the bulb and tube alone, but it is often more convenient to dismount the entire instrument from its position in the kiln. Because of the size of each bulb and the construction of the instrument, recording thermometers respond less quickly to temperature changes than glass indicating thermometers. This natural lag requires that more time be given for the recording thermometer to adjust itself during calibration.

ADJUSTMENT OF RECORDING THERMOMETERS

Calibration shows how the error of an instrument, if any, varies throughout its operative range. Errors are usually of two types, constant and cumulative. Sometimes, however, derangement of the mechanism may cause erratic errors. Constant errors, in which the pen reading of a recording thermometer is off the same amount throughout the entire range, can be corrected by adjustment of the pen arm itself. For making this adjustment there is usually provided a small screw at or near the pen-arm pivot, the turning of which moves the pen over the scale. Cumulative errors, in which the error increases or decreases progressively as the temperature rises, can be corrected in some makes of instrument by changing the leverage of the pen arm or the effective length of the hollow spring. Such adjustment is rather delicate and should not be attempted by unskilled hands.

Most recorders operate over a comparatively small range and it usually is possible to adjust them at the kiln so that they will be sufficiently accurate within this range. The adjustments should be made during the calibration in water, and should be checked for accuracy before remounting the instrument. If it has been possible to do the calibrating with the case and the bulb at the relative elevation they assume in the kiln, probably no further adjustment will have to be made. Once a thorough check of the instrument has been made, the usual calibrations in place should suffice as long as it remains in proper operating condition.

SERVICE CHECK OF CALIBRATION AND ADJUSTMENT

After a thorough calibration in the manner described the instrument should be remounted in the kiln and then again checked up at several points in its range by comparison with a standard thermometer hung close beside its bulb. Such comparison can well be made during the next run, if care is taken to read the instruments only after the temperature has been practically constant for 10 minutes, to allow the recorder bulb to overcome its natural lag. Simple further adjustment of the instrument, if it is necessary, may be made after securing check readings sufficient to show what is required.

PECULIARITIES OF DIFFERENT TYPES OF RECORDERS

It must be remembered during the calibration of recording thermometers that the three types, vapor-filled, gas-filled, and mercury-filled, do not behave alike. The elevation of the bulb, with respect to the case, has an important effect upon the reading of both the vapor-filled and the mercury-filled types; raising or lowering the bulb will move the pen arm up or down. Hence final calibration of recorders of either of these two types must be made with the bulb and the case of each instrument at the relative elevation they will have in service. With the gas-filled type, on the other hand, such manipulation has no effect upon the reading. Again, variations in either the tube or the case temperatures or both may affect the reading of gas-filled and of mercury-filled recorders, and important changes in these temperatures

must be guarded against during calibration and in so far as possible during use, although this matter is not at all important with vapor-filled instruments.

CALIBRATION OF WET-BULB INSTRUMENTS

Wet-bulb recorders also should be calibrated regularly, preferably without the wick, as frequently as the dry-bulb recorder and in a similar manner; double-pen instruments should have both bulbs calibrated, dry, at the same time. An occasional check with a wet and dry bulb thermometer will show whether the wet bulb is really recording the wet-bulb temperature. When making such checks it must be kept in mind that a reasonable amount of circulation past the bulb is necessary to secure evaporation enough to bring the actual temperature of the bulb down to the value correct for the conditions existing.

SERVICE CALIBRATIONS

Recorders of all types should be calibrated in place at least once every two months, and oftener if they show a tendency to fluctuate abnormally. They should be handled carefully, in accordance with the manufacturer's instructions, special pains being taken in changing charts not to bend the pen arm, and when filling the pen not to spill ink down the arm. Instruments should be returned to the manufacturer when other than the clock mechanism needs repair. Competent jewelers can keep the clocks in order.

INSTALLATION OF RECORDERS

Although recording thermometers can be obtained in weatherproof cases which need no special protection from the elements, it will be found advantageous to mount them in the operating room in some place that is readily accessible and as free from temperature changes as possible.

RECORDER CONTROLLERS

The manufacturer's instructions should be followed with especial care in the calibration and adjustment of recorder controllers. The calibration of the recording mechanism can be made in general in the manner outlined for recording thermometers. In some types, however, the thermostat mechanism interferes with the movement of the pen arm when the position of the setting arm or pointer fails to correspond to that of the pen arm. Hence it is desirable that the setting arm be moved in unison with the pen arm during calibration so that any possible interference effect may be avoided.

The adjustment of the setting arm must be made with the instrument in place and air pressure on. It also is desirable to have the temperature of the bulb within the usual operating range of the instrument. Starting with the setting arm well below the temperature of the bulb, move it, by means of the key or other mechanism provided for that purpose, until the diaphragm valve on the steam line opens, and note the position of the arm. Then move it further, until the valve closes, again noting its position. The last movement

will be small—perhaps about 2° on the chart. Now place the setting arm halfway between these two positions and adjust the pointer (there is usually a simple screw adjustment on or near the arm) until it corresponds to the temperature indicated by the recorder pen.

THERMOSTATS

Thermostats as a rule require no calibration other than the determination that, with a wet-bulb instrument, the circulation past the bulb is sufficient to insure proper depression. Such determination can be made by means of a wet-bulb thermometer placed right at the regulator bulb. The test must be made under actual operating conditions, since the air circulation past the bulbs may be quite different under other conditions. The thermometer should be read as soon as it has reached a constant indication and should then be vigorously fanned. If this fanning produces an additional drop in the reading of the thermometer, the normal circulation is inadequate.

It is necessary, however, to give the thermostat regulators occasional attention. With a self-contained instrument, which has a stuffing box on the valve stem, a small quantity of oil and graphite applied occasionally to the stem at the box will help to reduce friction, thus making the instrument more accurate. The stuffing box should be tightened only enough to prevent leakage. In the air-operated type the small valves in the regulator head must be kept free from the oil that is apt to be carried by the air. An occasional washing of the head, by disconnecting the air lines and pouring gasoline through it, will keep the parts clean, thus preventing sticking.

DRYING OVENS

The drying oven needs no particular attention, except to make sure that it is maintaining an average temperature of 212° F. and that its maximum variation, between limits, is not more than 5° F. Noticeably different values of oven temperature give appreciably different results in the moisture-content determinations. Steam ovens are easily regulated by means of a reducing valve in the steam main, and electric ovens by an adjustable thermostat operating on the heating circuit.

SCALES AND BALANCES

REQUIREMENTS

Scales for weighing samples and sections should be sensitive to the smallest quantity that they are intended to weigh; if they are not, they should either be repaired locally, returned to the factory for adjustment or replaced. The absolute accuracy of the scales, however, is not of paramount importance, as long as all the readings are in proportion. Thus, supposing for instance that a certain scale is constantly 5 per cent in error, the error will apply just as much to the original and the current weights as to the oven-dry weight, and the moisture percentages will work out just the same as they would if the scale were accurate, provided, of course, that all the weighings are made on the same one. This single example is sufficient to show that it is not absolutely necessary to have a set of standard weights for calibration. It is necessary, however, to be certain that the indi-

cated weights are always in proportion. If, for instance, one sample weighs twice as much as another, the scale must show that fact. Specifically, this means that all of the weights and the poise must be in proper proportion. Such a condition can be readily determined on platform scales by any scheme which allows the same piece or the same quantity of material to be weighed in turn with the different loose weights and with the poise.

CHECKING THE PLATFORM SCALE

Consider, for example, a 100-pound silk scale that has a single poise and a beam graduated to 2 pounds by hundredths of a pound, and loose counterpoise weights of 50, 20, 10, 10, 5, 3, and 2 pounds, respectively. This scale can be checked up as follows: Balance the beam accurately, set the poise at 2 pounds, and place just enough material on the platform to balance. Then return the poise to zero and put the 2-pound loose weight on the counterpoise. The beam should balance again. If it does not, the 2-pound loose weight and the poise are not of the proper relative weight. To ascertain the degree of error, balance the beam by changing the weight of the material on the platform. Then remove the 2-pound loose weight and balance the beam again by sliding the poise. The reading on the scale then indicates the weight of the 2-pound weight in comparison with that of the poise; if the loose weight is heavy enough to make it necessary, set the poise at the 2-pound reading, remove material from the platform until the beam balances, and get the weight of the material removed. Having checked the 2-pound weight against the poise, check the 3-pound weight by putting enough additional material on the platform to balance at 3 pounds with the poise set at 1 pound and the 2-pound weight on the counterpoise. Remove the 2-pound weight, return the poise to zero, and place the 3-pound weight on the counterpoise. This scheme of comparisons may be continued through the entire capacity range of the scale. It is most convenient, in securing the final balance of the beam at the different weights, to use a pan of shot, sand, or water for the material.

CORRECTING ERRORS IN THE WEIGHTS

After all the loose weights have been compared with the poise, consideration may be given to the correction of errors. If all the loose weights seem to be either too light or too heavy, the poise itself probably is too heavy or too light, and hence its weight should be corrected. The usual method of lightening is by drilling or filing; weight may be increased by adding metal, usually lead or solder. Care should be taken to see that any metal added will stay in place.

If the errors in the loose weights are erratic, the assumption is that the individual weights are incorrect, and they should be changed accordingly.

CHECKING THE BALANCE

A balance in which loose weights are used can be checked, after the beam has been balanced with the pans empty, simply by interchanging the contents of the two pans. If the pans were in balance

in the first place and remain so, the arms must be of equal length. If the arms are not of equal length, the balance can still be used, by always placing the weights on the same pan. The individual loose weights may be checked against one another by placing the same nominal weight on each pan.

One common type of equal-arm balance intended for use with loose weights has a scale beam and rider for the final balancing. When checking this type of balance for equality of beam length by interchanging the weights between the pans, the rider must be set at zero. For checking the rider itself, one of the small loose weights may be placed upon the left-hand pan, which is the one intended for the material to be weighed, and weighed by the rider.

ADJUSTMENT AT NO LOAD

Practically all scales and balances have a means for securing accurate balance at no load, in the beam type usually either loose shot in a chamber in the base of the counterpoise or a moveable threaded counterweight carried on a reverse extension of the beam. Making the adjustment to obtain such balance is the first step in checking.

PRESSURE GAUGES

Steam and air pressure gauges, if used simply to give a general idea of the amount of pressure available or to check the operation of a reducing valve, need not be very accurate. The operator, however, should know how to calibrate them so that he may do so when necessary. Two general methods of calibration are in common use; in one the gauge is compared directly with a standard test gauge and in the other the pressure to which the gauge is subjected is determined by means of standard weights on a piston of known diameter. In both cases the test pressure is produced by means of a small, oil-filled hand pump that is provided with connections for the gauges and the gauge tester. Testing equipment for light field work is carried by all boiler inspectors. If none is available, comparisons can often be made with other gauges, such as those on the boilers, and a fair idea of the accuracy of the kiln gauges obtained in this manner.

The gauge under test is subjected to pressures within its range, and its errors of indication are noted. Ordinary adjustment of minor errors can often be made by pulling the gauge hand from its spindle and putting it back again in the proper position. If the fault is of a nature such that resetting the hand fails to correct it, the gauge should be returned to the manufacturer for repair.

LOCATION OF INSTRUMENT BULBS

The drying schedules in this bulletin are based on the assumption that the temperature and the humidity in the kiln are both measured and controlled at one of the points where the air enters the lumber pile. The drying conditions at such points are the most severe, since the air constantly becomes cooler and more moist as it travels through the lumber.

Only a thorough examination by means of the smoke test and of thermometers hung in different parts of the kiln will determine

where the recorder and the regulator bulbs must be hung in order to secure exposure to conditions corresponding to those of the entering air. After the placing of the instrument bulbs correction can be made in the setting or the reading of the instruments proper. In cross-piled kilns and in the single-track end-piled type without central chimneys in the lumber piles, bulbs are often hung on the wall, since removing and replacing them in such kilns each time the charge is shifted is considered not worth while. Further, the circulation in these kilns is frequently such that no definite entering-air point can be determined.

In compartment kilns, such as the one in Figure 11, the bulbs can be placed in the central chimney formed by the lumber, which is the proper place for them. They should be at least 15 feet from the end of the kiln and should also be fully 6 feet above the heating coils unless they are shielded from direct radiation.

In external-blower kilns the bulbs are sometimes placed within the entering-air duct, but it is considered better practice to place them within the entering-air chimney in the lumber pile, 4 or 5 feet above the duct. The air is more representative of entering air at this point than within the duct. If the heating units are in the form of pipe coils within the kiln, the bulbs must not be placed in the air duct.

In the internal-fan kiln the fans are usually operated so that the air circulation remains in its initial direction only during the first part of the drying; the bulbs should be located in what is entering air under these conditions. Most internal-fan kilns are of single-track design; in edge-stacked kilns of this design the proper place for the bulbs is in a side flue, and in flat-piled kilns it will usually be necessary or at least expedient to put them in this location also, even though the logical place in such kilns, in general, is in the central chimney within the lumber pile. In double-track flat-piled kilns of the internal-fan type the proper place for the bulbs is in the central chimney between the two rows of trucks. For all of the locations suggested, when the circulation is reversed, the bulbs will be in a cooler leaving-air current, and consequently the dry-bulb thermostat will probably have to be lowered a few degrees so that the entering-air conditions may remain constant. The wet-bulb thermostat will usually require no change, since the drop in wet-bulb temperature during the passage of the air through the lumber is negligible.

A special type of vapor-filled thermostat has been developed for temperature control in reversible-circulation kilns. The wet-bulb thermostat has the usual single bulb, which may be placed as already indicated. The dry-bulb thermostat, however, has two bulbs and two extension tubes, both connected to the same tube system. One dry bulb is placed near the wet bulb and the other in an opposing flue, that is, a flue that carries leaving air when the other carries entering air and conversely. The properties of a system of this kind are such that the instrument is automatically actuated by the bulb having the higher temperature, namely, the entering-air bulb. Thus as the air circulation is reversed, the control is automatically shifted from one dry bulb to the other.

THE PLACING OF KILN SAMPLES

A large number of samples, 10 or 12, should be used for each run until the behavior of the kiln is well determined. The position of these samples is of prime importance; faulty position will render them valueless, for their sole purpose is to represent truly the conditions in the kiln. They should be so placed in the piles of lumber that they will receive exactly the same drying treatment as the lumber itself, that is, they should be located on both entering-air and leaving-air sides of the piles, high, low, and halfway up, to permit determination of the various relative drying effects. In case of erratic circulation or of trouble from uneven drying, samples can also be placed in the middle of the piles; no intermediate weighing of these will be possible. With progressive kilns, or in fact with any type operating at high temperatures, the obtaining of intermediate weights on any of the samples is often a difficult matter.

THE KILN RUN

STEAMING

If the stock is to be steamed, this operation may be started as soon as the kiln has been loaded, with the samples in place. A full supply of high-pressure steam should be available, so that the steaming temperature may be reached quickly. Care must be taken to prevent possible injury to the instruments as the kiln is heated; the steaming temperature will often be higher than that for which the regulators are set, and if these are of the liquid-filled type the excessive pressure developed may strain the bulbs or the diaphragms or cause the valves to stick on their seats. The obvious way to avoid such a situation is to set the regulators higher during steaming. When the steam sprays are automatically controlled this will be done in any event.

DETERMINING THE CIRCULATION

After the drying conditions have been established a study should be made of the circulation. This study can well be supplemented by the use of a number of wet and dry bulb hygrometers scattered throughout the kiln, preferably near the different samples. The readings of properly placed hygrometers will give a good idea of the relative drying conditions in the kiln. After tabulation of the readings, the corresponding relative humidity values should be determined. The variation in the relative humidity is a good indication of the variation to be expected in the drying rate throughout the kiln. If wet and dry bulb hygrometers are used in progressive kilns to determine the degree of uniformity of drying, they should all be placed in a single pile at any one time, since variation from end to end of the kiln is to be expected. Studying the lengthwise variation, however, may be desirable; for this purpose a number of hygrometers should be distributed throughout the kiln length.

OBTAINING HUMIDITY READINGS AT HIGH TEMPERATURES

Entering a high-temperature kiln under its full operating temperature frequently is impossible. Hygrometers can often be let down through vents or other holes in the roof of such a kiln and

withdrawn for reading; obviously they must be read immediately unless they are of the maximum-reading type. When it becomes necessary to enter a hot kiln an assistant should always be on hand for help in case of emergency.

DRESSING TO WITHSTAND KILN TEMPERATURES

A certain degree of protection against heat at the operating temperatures of the kiln may be secured by the use of extra heavy clothing, preferably wool, of heavy, rivetless leather gloves, and of a mask or a hood. A gas mask with a special ice-filled container will cool air for breathing. To secure greatest results from heavy clothing it should be as vapor-tight as possible from the soles of the shoes to the top of the head. The wet-bulb temperature, rather than the dry-bulb value, is the prime determining factor in the matter of physical discomfort. An atmosphere with a wet-bulb temperature of 135° F. or higher can not, as a rule, be withstood unprotected long enough to make entry into the kiln practical. If a smoke machine is to be used at such a temperature, a 2-valve rubber syringe bulb should be fitted to its mouthpiece.

WEIGHING KILN SAMPLES

The samples should be weighed frequently enough to determine accurately their changes in moisture content. The percentage of moisture should be calculated immediately after each weighing, and a chart, showing graphically the loss of moisture day by day, should be maintained. The daily temperatures and humidities may be plotted on this same chart, which can then be compared with the drying schedule for the detection and the correction of differences. Plotting the temperature and the humidity of the schedule on the same sheet will provide the most convenient means for comparison of the schedule and the actual run. (Fig. 14.)

KILN RECORDS

In addition to a kiln-performance chart, it is desirable to keep a permanent record of the other details of each run. Forms for this purpose are provided by some of the kiln manufacturers and can well be used wherever they are applicable. Many an operator, however, prefers to make up his own form.

Excepting for the most simple class of routine drying, each run in any kind of a kiln should be identified fully, to permit quick and positive reference to the kiln-performance record covering it. Then, if trouble subsequently develops with any lot of stock, examination of its history will usually show the cause. Naturally this cause may be some factor in its life before it reached the kiln rather than in its handling through the kiln, but only adequate records will disclose that fact. A run in a compartment kiln may be identified by number or by date; both means are preferable to either alone. The record of a progressive kiln of necessity is kept by days; each truck load of lumber going through such a kiln can be numbered—it is common practice to do so—and then in addition should be tied in with the kiln record by dates showing the time both of entering and of leaving.

Although records other than the kiln record will provide for some necessary information, the kiln form should be inclusive rather than exclusive, with extra blank spaces for occasional special data. Convenience, as well as wisdom, almost demands that a copy of all other pertinent records be filed with the kiln record.

An operator doing custom drying of course requires some information not needed by others, just as one handling stock from many

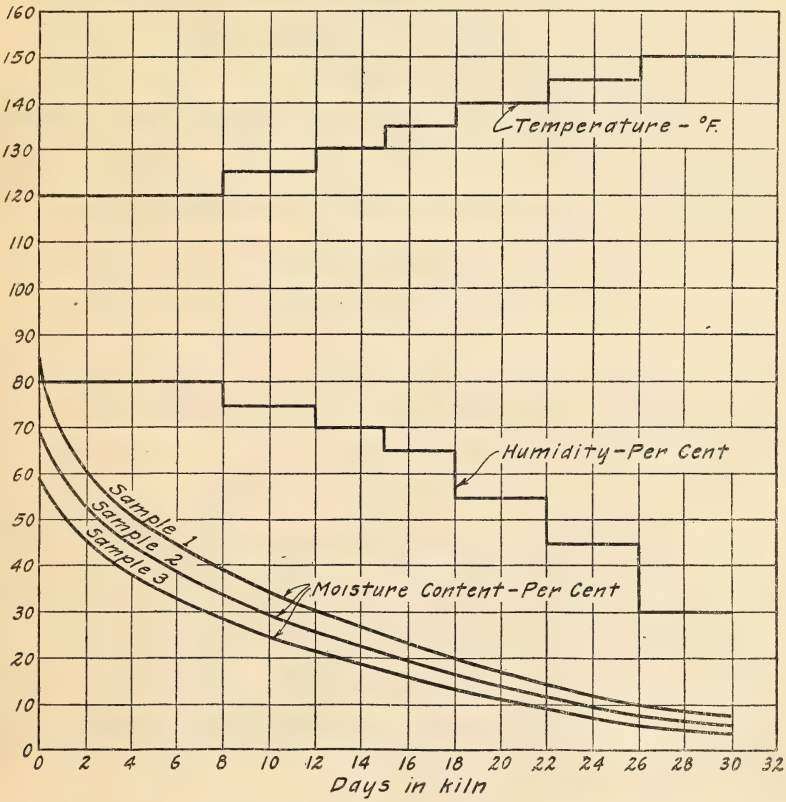


FIGURE 14.—The probable appearance of the plotted record of a kiln run that followed general hardwood Schedule 5 accurately and took 30 days for completion. Records of any conditioning treatments that may have been given are omitted for the sake of simplicity. The three moisture-content curves are intended to show the current moisture-content values of three kiln samples. The temperature and humidity graphs are plotted directly from Table 2 on page 49

and diverse sources carefully records data that are of slight value to the man drying only the product of a single mill drawing its supply from the same stand. Hence individual conditions will modify somewhat the following list of suggested headings for the kiln record form.

1. Name of the company drying the stock.
2. Name of the operator.
3. Kiln number.
4. Run number.
5. Date and hour of the beginning of the run.
6. Date and hour of the completion of the run.

7. Number of hours in the kiln.
8. Name of the manufacturer of the stock to be dried.
9. Date of the arrival of the stock at the yard.
10. Name and number of the railroad car that carried the stock to the yard.
11. Species of wood.
12. Locality in which the wood was grown.
13. Moisture content of the stock on its arrival at the yard.
14. Appearance of the stock as to seasoning defects.
15. Time of air seasoning when the stock enters the kiln.
16. All important dimensions of the stock, including the range in length.
17. Number of board feet on each truck.
18. Size of the stickers and species of wood used for them.
19. Number of tiers of stickers to the truck.
20. Use for which the stock is intended.
21. Final moisture content desired.
22. Original weight, final weight, and moisture content of each preliminary moisture section cut from a kiln sample.
23. Original weight, original moisture content, and calculated dry weight of each kiln sample.
24. Running record of the current weight and the calculated moisture content of each kiln sample.
25. Original weight, final weight, and moisture content of each moisture section cut from a kiln sample at the end of the run.
26. Running record of the kiln temperature, together with the hour at which each reading was taken. (Two or more readings a day are desirable.)
27. Running record of the kiln humidity, corresponding exactly to the temperature record.
28. Identification number of each thermometer used in the run and the correction to be applied to its readings.
29. Running record of the appearance of the stock, of stress determinations, and of high-humidity treatment.
30. Final moisture content of the stock.
31. Unusual conditions of any kind, general or specific.

The charts from the recorders, with run number, dates, and corrections plainly indicated on each, should be filed with each run report, and final stress sections can frequently be kept to advantage, at least until the stock has been worked up. To make the marking of kiln samples simpler, each one may be given the run number and an additional individual serial number. Thus, if there are four samples in run 32, they may be numbered 32–1, 32–2, 32–3, and 32–4, respectively. Moisture sections cut from the sample should bear the sample number and also an individual identifying number or letter. The two sections first cut from 32–1 may be marked 32–1A and 32–1B, and the final section 32–1C.

ESSENTIAL APPARATUS

In order to work effectively, every operator should have certain apparatus and a suitable workroom in which to keep and to use it. The following list represents the minimum equipment compatible with efficient work:

One standard-grade etched-stem glass chemical thermometer, 30° to 220° F., graduated in degrees.

Six wet and dry bulb hygrometers, 60° to 220° F., graduated every second degree, with spare wicks.

One balance or trip scale for weighing moisture sections; see page — for a discussion of the various balances available for this purpose.

One platform scale or balance for kiln samples, capacity 100 pounds, sensitive to one one-hundredth pound, the beam graduated to one one-hundredth pound, or—

A solution scale, capacity 20 kilograms, sensitive to 1 gram; two scale beams, one graduated to 100 grams in 1-gram units, the other graduated to 1,000 grams in 100-gram units; counterpoise and loose weights.

One drying oven (electric or steam), inside dimensions at least 10 by 12 by 10 inches, to operate at 212° F. Thermostatic control for the oven accurate to within 2° F.

One 10-inch slide rule.

One smoke machine with concentrated hydrochloric acid and strong ammonia water.

Two flash lamps; spare batteries and lamp bulbs.

If hot end-coatings are to be used, a kettle and a hot plate or a stove will be needed.

A small motor-driven band saw for cutting samples and sections will in many cases prove an excellent investment. For high-temperature kilns two maximum-reading wet and dry bulb thermometers, 60° to 220° F., graduated every second degree, will be found very useful.

Miscellaneous tools, such as screw drivers, pipe wrenches, pliers, a saw, a hammer, and a rule.

For identification purposes each instrument should be numbered before it is put into service. A metal tag attached to the casing or to the support is convenient for this purpose when numbers can not be stamped or etched directly on the instrument itself.

AIR SEASONING

Discussion of the air seasoning of wood falls outside of the province of this publication, except in so far as a knowledge of it is essential to the kiln operator. Much of the lumber dried in kilns, especially hardwood lumber, however, is first air-dried, either at the sawmill or at the manufacturing plant, and the quality of the finished product depends in no small measure upon the care taken in the preliminary air seasoning.

Piling correctly for air seasoning must accomplish a number of things: It must provide proper air circulation, it must offer suitable protection from sun and rain, and it must keep the boards straight and flat while they are drying. If these things are accomplished, the best drying will result, and drying defects will be at a minimum. Among such defects may be mentioned stain and decay, end and surface checking, and warping.

No one rule will apply to all weather conditions and to all classes of stock; often, however, no special precautions have to be taken to prevent too rapid drying, while on the other hand every effort should be made to secure ample air circulation through the pile.

The following general principles will apply to most seasoning yards:

Foundations for lumber piles should be firm, and level in one direction and properly pitched in the other. Standing well above the ground, preferably high enough to give a 12 to 18 inch clearance above the ground at the lowest point, they should provide adequate support for each row of stickers and keep the lumber entirely free from decay. Free circulation of the air under the stringers and around all parts of the foundations must be secured.

Pile widths should be kept small when possible. A 6-foot width is an excellent minimum for most hardwoods. Softwood piles can usually be wider—8 feet and upward. When softwoods are stickered with stock (self-stickered) instead of with special stickers the width

of the pile will of course equal the length of the stock. Low grades of softwoods, especially in narrow widths, are often self-stickered.

Spaces between adjacent piles should be ample—4 feet if possible—and spaces between rows of piles should average 8 feet or more; main alleys should be about 16 feet wide.

Stickers should be of clear, dry stock, entirely free from both stain and decay, not less than 7/8-inch thick, and from 1½ inches wide or more for hardwoods to 4 inches or less for softwoods. They must all be of the same thickness. The spacing between rows of stickers will vary from 2 feet minimum, for green hardwoods such as red gum, to 6 or 8 feet maximum, for softwoods. Under most conditions, 8 feet will be found too wide a spacing even for softwoods. Front and rear stickers should project an inch or so beyond the ends of the boards.

The piles should pitch forward about 1 inch in 12 inches and should slope downward toward the rear the same degree.

Roofs for lumber piles, which ordinarily are made of common grades of lumber, must provide protection from sun and rain; such roofs often are used repeatedly but in some instances are disposed of after they have been used a few times. They should be made of two overlapping layers of boards, should project at least a foot on all sides of the pile, and may if desired be given a greater slope than the pile itself. This may be done by elevating them above the top of the pile 4 inches at the rear and 8 inches at the front. In windy localities they may have to be anchored to the pile.

Spaces between boards in the same layer should usually be from 2 to 4 inches. As far as possible, the corresponding spaces in successive layers should be in vertical alignment. In large piles a single central chimney or two or more side flues may be formed by the method of piling in order to hasten drying. The lower parts of piles usually dry more slowly than the upper parts, and it is often desirable to open up the lower portions to counteract this tendency.

In general, overhanging ends of long boards should be avoided. To do this, when it is necessary to pile boards of uneven length together, they should be box piled, either exactly as described on page 80 for kiln work or possibly with some slight modification of that method. In any event, both ends of each board must be supported, and no board should be placed on a sticker that is not itself supported by a board underneath it.

If drying is too rapid, as evidenced by excessive checking, the circulation should be cut down by using thinner stickers, wider piles, or narrower spaces between boards; by spacing the piles closer together; or by a combination of these means. If drying is too slow, as evidenced by staining, the opposite course should be pursued.

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